TECH ALERT: Facial recognition software is watching YOU p.30

Discover

SCIENCE FOR THE CURIOUS

December 2015

Hunt for the First Stars

What the earliest suns reveal about the universe's origins p.38

PLUS

Why Pluto Matters p.70

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An NYPD security camera peers down on Times Square in Manhattan.

ON THE COVER *Illustration by Roen Kelly*

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OPPOSITE: YANA PASKOVA. THIS PAGE FROM TOP: FRANCISCO NEGRONI; CARRIE L. WOODS

Editor's Note

A Tangible Offer

Praise for our columns (and a dubious Space Age drink).

As a kid, grape-flavored Tang was my beverage of choice. I suppose it's not entirely appropriate for me to mention a commercial product in an editor's note, but grape Tang is impossible to find in stores these days, so what's the harm? In any case, I don't think of Tang as a product, but as a fixture of my early youth, when we had only recently been to the moon, when Skylab still flew overhead, when my taste buds really had no idea what they were doing.

From those days to now, I had believed that Tang was designed for the U.S. space program and therefore the preferred beverage of astronauts everywhere. As you'll see in this month's History Lessons (page 66), I was wrong on both counts. But I learned something new, both about the origins of my childhood favorite and about the trial-and-error process the space program went through to make sure its astronauts were at least well nourished, if not precisely well fed.

Every issue I learn something new from our range of regular columns, whether it's historical science in History Lessons, details about human development in Origin Story, fascinating medical facts in Vital Signs or news about the environment in Notes From Earth. Out There, our astronomy column, is always illuminating, as is Mind Over Matter, our mind/brain column. And Big Idea, which in any given issue could cover any stunning science topic, regularly blows my mind.

Is there a science topic we don't cover in one of our columns that you'd like to see in future issues? Email me at editorial@discovermagazine.com and tell me about it. If we turn your idea into a new column, I'll buy *you* your beverage of choice — yes, even grape Tang, if I can manage to find it.

NEXT ISSUE: *Get ready for our biggest issue of the year as we unveil the top 100 science stories of 2015. See you next time with the Year in Science!*

Stephen C. George, EDITOR IN CHIEF

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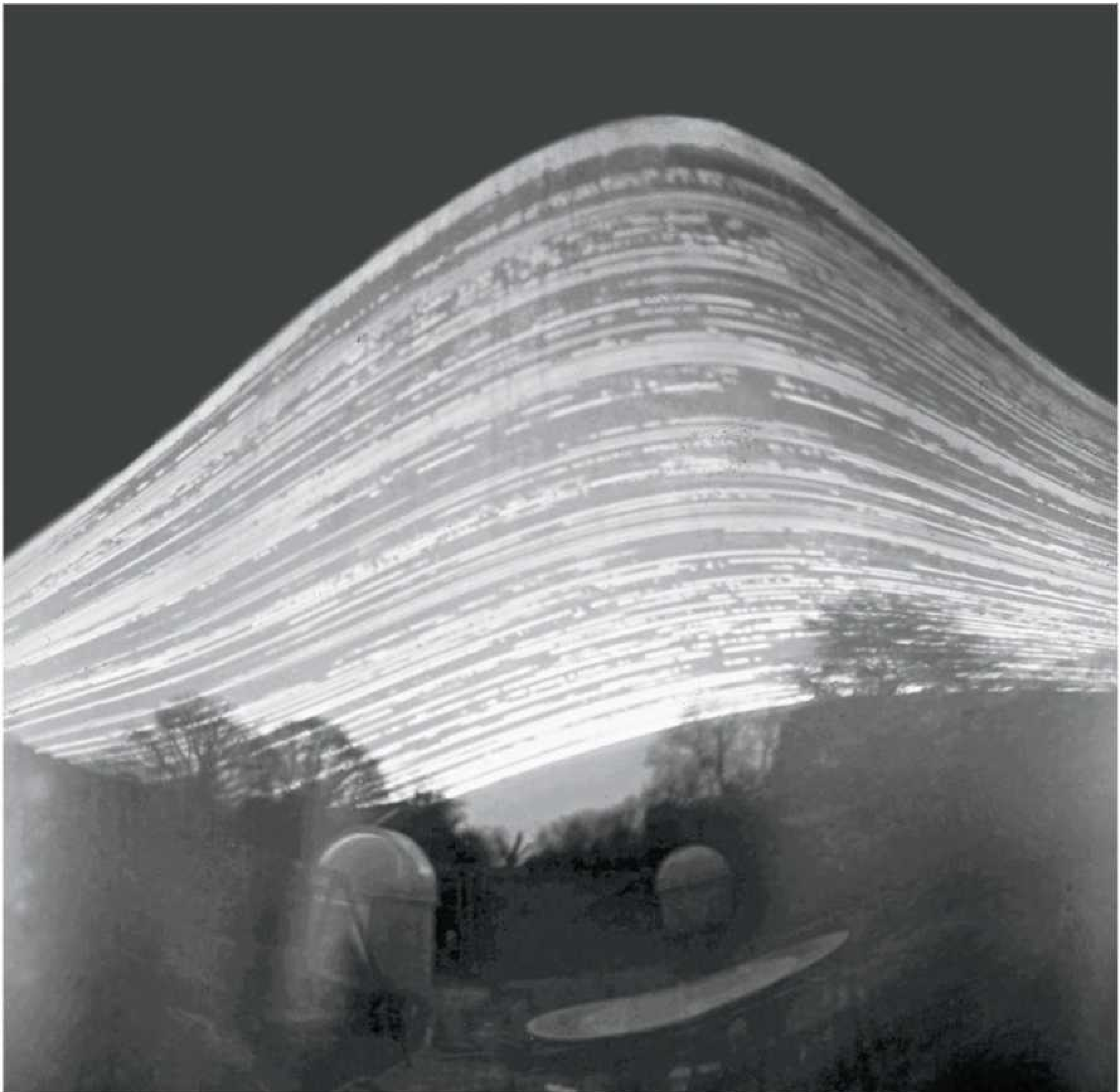
WILLIAM ZUBACK/DISCOVER

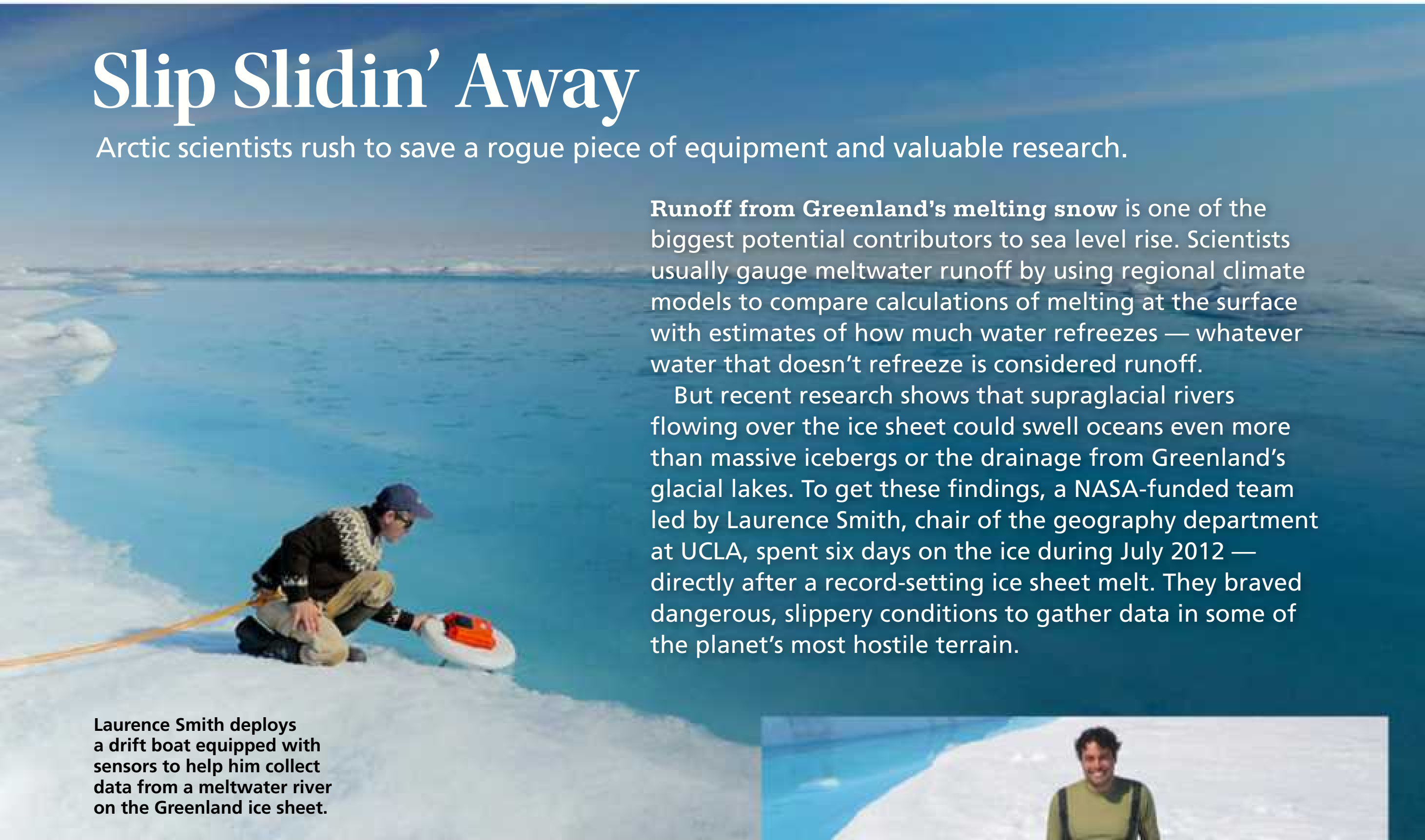
THE CRUX

The Latest Science News & Notes



SOLSTICE SUNBURN

The wide-striped band that dominates this ghostly view of a southern English yard is actually the track of the sun across the sky, climbing gradually higher from the winter to summer solstices. To create this image, retired photonics professor Greg Parker made a cylindrical pinhole camera using a plastic pipe 4 inches wide. He loaded it with a sheet of light-sensitive photographic paper and left the pinhole — literally just a hole on the curved side — open from Dec. 21, 2013, to June 21, 2014. Breaks in the bright streaks indicate clouds.
— ERNIE MASTROIANNI; PHOTO BY GREG PARKER



Slip Slidin' Away

Arctic scientists rush to save a rogue piece of equipment and valuable research.

Runoff from Greenland's melting snow is one of the biggest potential contributors to sea level rise. Scientists usually gauge meltwater runoff by using regional climate models to compare calculations of melting at the surface with estimates of how much water refreezes — whatever water that doesn't refreeze is considered runoff.

But recent research shows that supraglacial rivers flowing over the ice sheet could swell oceans even more than massive icebergs or the drainage from Greenland's glacial lakes. To get these findings, a NASA-funded team led by Laurence Smith, chair of the geography department at UCLA, spent six days on the ice during July 2012 — directly after a record-setting ice sheet melt. They braved dangerous, slippery conditions to gather data in some of the planet's most hostile terrain.

Laurence Smith deploys a drift boat equipped with sensors to help him collect data from a meltwater river on the Greenland ice sheet.

Alberto Behar with the remote-controlled drone boat he helped design. His quick thinking helped his team recover the drone, which held valuable data, when it drifted beyond its remote signal.

IN HIS OWN WORDS

One morning, our helicopter pilot gingerly approached the shore by that day's destination, Lake Napoli, maneuvering to find a solid spot to land safely. We chose this particular lake because it wasn't far from one of the supraglacial river sites where we'd been working, and it was so massive — about a mile in diameter. Plus, it was only about 40 to 50 miles from our base camp in Kangerlussuaq, a settlement in the western part of Greenland.

As with every other day of the trip, the weather cooperated and we had blue skies, but we knew the terrain could be treacherous — parking a helicopter on slushy, melting ice is not trivial.

Alberto Behar, of NASA's Jet Propulsion Lab, who was part of our team and with us on the expedition, designed a remote-controlled drone boat we used to collect data. It maps the depths and reflectivity of meltwater on the ice surface and is a one-of-a-kind piece of equipment built for this very specific application. The parts alone are valued at more than $50,000.

On this particular day, we deployed the drone boat, operating it by joystick from the shore. But the lake was so unexpectedly vast that the boat disappeared over the horizon, and it was not responding to the controls.

I thought it was lost, which would've meant that a crucial part of our fieldwork was scuttled — we wouldn't have been able to do many of the critical measurements that we went there to do. But Alberto ran to the helicopter, we all jumped in and choppered out to the lake. After several nerve-racking minutes, he got back in [the drone's] radio range. Alberto operated it by joystick from the helicopter and got it back to the shore. That was a very valuable piece of equipment, and he saved it.

—AS TOLD TO LINDA MARSA

FROM TOP: NASA GODDARD SPACE FLIGHT CENTER/JEFFERSON BECK; LAURENCE SMITH/UCLA

Bye-Bye, Blood Clots

Surface-coating technology prevents blood from clotting in medical devices.

Blood thinners are necessary for many life-saving procedures. Yet for trauma victims with multiple injuries — like car accident victims or wounded soldiers — using anti-coagulants can accelerate potentially fatal blood loss.

A solution to this problem was inspired by technology engineered to prevent ice from adhering to airplane wings. Researchers from Harvard's Wyss Institute treated medical devices, such as catheters, with a special coating that repels the components of blood that would otherwise form clots on the devices and cut off needed blood flow.

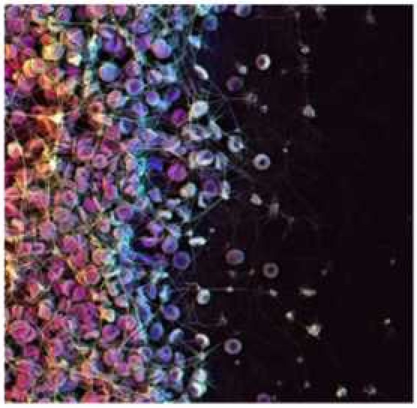
The coating is made of two layers of a synthetic chemical, similar to Teflon, called perfluorocarbon. The substance creates a slippery surface for the sticky parts of blood — fibrin and platelets — to slide past.

The team tested the technology in pigs by inserting catheters and other medical devices coated with the perfluorocarbon. They even challenged a gecko to climb up a coated surface. Geckos derive their incredible climbing ability by using a lot of small, weak chemical bonds — the same chemical bonds that are the first step in blood clotting.

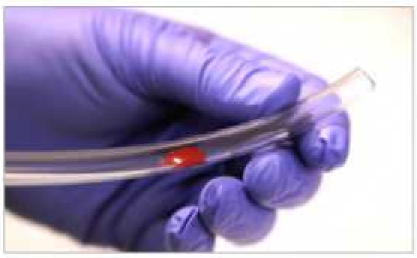
"The look on the gecko's face when he slides down is so humiliated," senior author Dan Ingber said.

Perfluorocarbon is already used as an FDA-approved blood substitute and can be used in any procedure involving extracorporeal devices, such as dialysis machines. Plus, the perfluorocarbon coatings can be sterilized for medical use. Researchers are in talks with device-makers now.

— KATIE BO WILLIAMS



A microscopic view of blood cells forming a clot (above, left), which can clog implanted medical devices and harm patients. Harvard researchers used a special coating on such devices (like the medical tubing below) to prevent clots and eliminate the need for risky blood thinners.



Uncoated surface

Tethered-Liquid Perfluorocarbon (TLP) coated surface

WEB

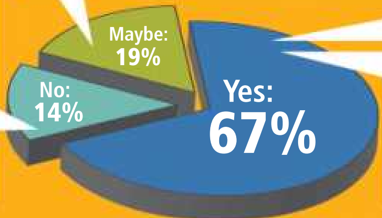
Finding E.T.

NASA chief Ellen Stofan recently made a bold statement about extraterrestrial life. "I believe we are going to have strong indications of life beyond Earth in the next decade and definitive evidence in the next 10 to 20 years," she told a public panel. We asked if you agreed. Here's what you said:

"Twenty years seems a rather short time frame to build and deploy the technology required to detect alien microbes, especially when we have no way of being certain where and what to look for."

"We have most of the pieces of the puzzle that we need to find evidence, but it will take time to collect that evidence in a reliable enough way."

"Our definition of 'life' is dramatically changing every year."



"We've already got the building blocks of life discovered on Mars, and the ice moons with active geologic processes."

From Twitter

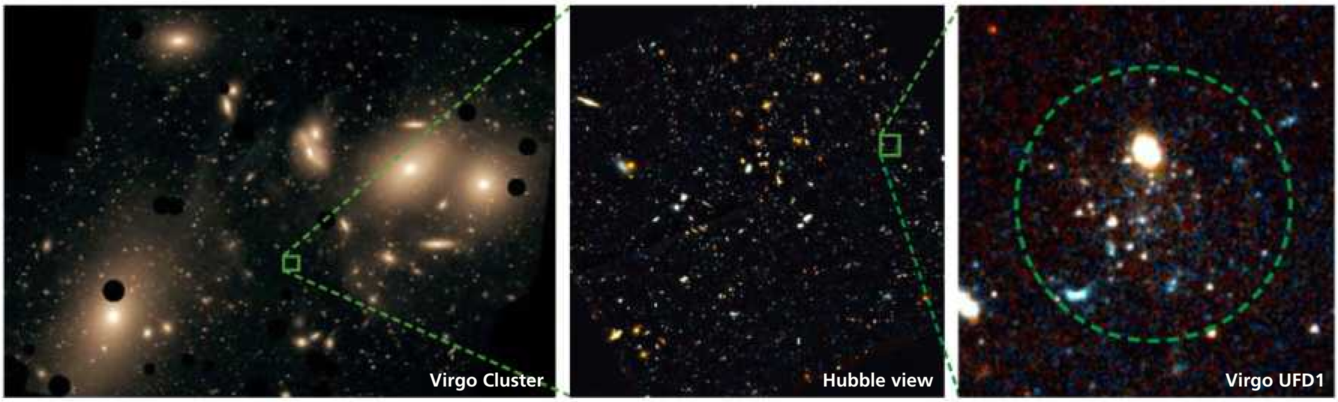
One reader recently credited us with jump-starting her interest in science when she shared her #MyScienceStory. Shauna Bennett now works at Scripps Research Institute as a scientist and communicator. We're #flattered.

"#MyScienceStory came from reading other scientists' stories when I was young in @DiscoverMag … now I want to spread science stories."
–@ShaunaMBennett

WYSS INSTITUTE AT HARVARD UNIVERSITY. PIE CHART: ALISON MACKEY/DISCOVER

Old Data Yields New Discoveries

Just because a mission's over doesn't mean it's done being useful.

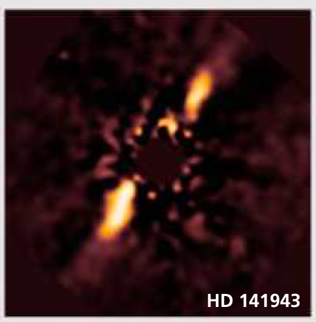


As Oscar the Grouch and garage sale aficionados know, you can uncover treasures while going through someone's old stuff. That's exactly how two astronomers from Seoul National University in Korea found an ancient, relatively close galaxy — by combing other researchers' leftovers.

Myung Gyoon Lee and In Sung Jang were looking for ultra faint dwarf (UFD) galaxies, remnants of the universe's first galaxies. They scoured Hubble telescope images up to 15 years old of a nearly empty region of space just outside the Milky Way, and their search paid off: Lee and Jang reported last year that they uncovered a tiny, faint galaxy called Virgo UFD1. It's the most distant UFD ever seen, and it formed almost 12 billion years ago. Not bad for dumped data.

Scouring others' observations for new discoveries is actually common among astronomers:

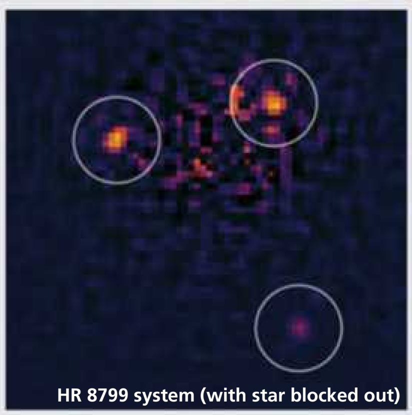
❶ In 2013, Rémi Soummer and colleagues reprocessed Hubble infrared data extending as far back as 1999. Where other scientists found nothing, Soummer's team discovered five stars (including HD 141943, below) with surrounding dust disks (below, right) — the breeding grounds of planets.


HD 141943


Artist rendering

❷ When looking through 15-year-old radio data from several observatories in 2013, astronomers found clumpy segments along a ring shape in our galaxy; when they searched for it in visible light, they came up empty. Francesco de Gasperin and colleagues believe they've spied an old stellar explosion whose material has mostly dispersed, making it invisible in optical light but leaving behind radio imprints at the site.

❸ Old Hubble data can also hide photos of extrasolar planets themselves. In 2008, astronomers photographed three worlds five to 13 times Jupiter's mass orbiting a young star, HR 8799. The following year, David Lafreniere found the outermost of those three planets in Hubble images from 1998, giving astronomers more data to calculate the planet's orbit.


HR 8799 system (with star blocked out)

❹ To find stars on the run, astronomers look for a curved buildup of material preceding the star, similar to the water in front of a speeding boat. In 2011, Vasilii Gvaramadze and colleagues scoured archived infrared data from two space telescopes for these telltale markings. They found seven belonging to massive stars escaping their birth clusters, showing how some stars begin their solo journeys through space.

—LIZ KRUESI

FROM TOP: MIHOS ET AL. 2005 (VIRGO CLUSTER); NASA/STSCI/IN SUNG JANG AND MYUNG GYOON LEE/SEOUL NATIONAL UNIVERSITY (2); NASA, ESA, R. SOUMMER AND M. PERRIN/STSCI; NASA, ESA AND R. SOUMMER AND A. FEILD/STSCI; NASA, ESA, STSCI, R. SOUMMER

Crowdsourced Seizure Prediction

A public contest makes the biggest seizure breakthrough in 15 years.

Fifty million people have epilepsy, and many suffer brutally unpredictable seizures. If the seizures could be anticipated, electrical brain implants could stop a nascent seizure in its tracks, or at least give patients warning.

For 15 years the National Institutes of Health and other agencies spent $40 million trying — and never quite succeeding — to devise algorithms that could spot a growing neurologic storm. Then a frustrated group of epilepsy physicians invited computer nerds around the world to take a shot instead, providing data sets recorded from the brains of human epilepsy patients and epileptic dogs.

Three months — and $30,000 of prize money — later, the winners had produced algorithms predicting seizures with better than 84 percent accuracy.

—GORDY SLACK

DAVID MACK/SCIENCE SOURCE

Genetics of Sexuality Broadens

Experts continue to hunt for variations linked to homosexuality.

In 1993, geneticist Dean Hamer co-published a study claiming male homosexuality was at least partially genetic, and he identified the chromosome segment where one of the relevant genes was located. It was just some of the research on the controversial topic that *Discover* unpacked in a June 2007 feature article, "Born Gay?"

Since then, researchers from Northwestern University and NorthShore University HealthSystem Research Institute in Evanston, Ill., have replicated Hamer's results in a larger, more robust paper — and they're working on a more sophisticated study.

Hamer looked at 76 pairs of gay brothers, while psychiatrist Alan Sanders recruited 409 pairs of brothers and used the same analysis Hamer used, called linkage analysis. Linkage studies use genetic markers, which act like signposts, pointing researchers to the general area on the chromosome where genes associated with certain traits likely reside. The study, published last year, found two strong links to homosexuality on different chromosomes, supporting Hamer's findings and suggesting that multiple genes are at work. It's not just a "one-gene, one-trait scenario," Sanders says.

One problem? "Linkage studies implicate pretty broad regions, so there's still a bit of work to be done to narrow it down," he says.

So Sanders' current research uses the same brother pairs, but it relies on a genomewide association study, a newer analysis that looks at hundreds of small genetic variations at a time.

June 2007 issue

The association study matches genetic variants with a trait by looking at large groups of people with that trait and then compares how their genomes differ from a group without the trait. The analysis helps researchers find a genetic association even when there's no genetic marker to guide them. — KATIE BO WILLIAMS

Ask Discover

Q How can you get used to eating spicy food? Do your taste buds change, or is there a psychological element at play?

— Alex Klunk, Chesterfield, VA

A Spicy food tolerance comes from a physical change in how some of the body's pain receptors react to capsaicin, the molecule responsible for the "hot" in spicy peppers and foods flavored with them. Psychology factors into how much we *like* the burn, not how we *feel* the burn.

The spicy heat (as well as temperature heat) is registered through specific receptors on the tongue's nerve cells. When exposed to capsaicin, these receptors open to allow in sodium and calcium ions, causing the receptors to transmit that hot signal to the brain. However, with repeated short-term exposure to capsaicin, those calcium ions essentially close the receptor door behind them, inhibiting further transmission of pain signals.

Over the long term, with repeated spicy meals, the whole nerve ending starts to degrade in a way scientists are still trying to understand. The nerves aren't permanently damaged, though, and can grow back. That's why it takes a regular diet of spicy food to keep the burn at bay. —LEAH SHAFFER

Visit **DiscoverMagazine.com/Ask** for more answers. To submit a question, send an email to **Ask@DiscoverMagazine.com**

DID YOU KNOW?

Farewell, Fido? As Earth gets ever more overpopulated, straining both food supplies and living spaces, an animal welfare researcher at the University of Melbourne predicts that flesh-and-blood pets will be replaced by companion robots, perhaps within the next 15 years.

FROM TOP: TERI VIRBICKIS/SHUTTERSTOCK; JULOS/ISTOCK

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- Joint Pain
- Back or Knee Pain
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- Arthritis
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- Bunions
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What's the Chin Good for?

The answer could be right under our noses.

For more than a century, anthropologists have wondered why we possess a chin when apes and our *Homo* ancestors are chinless. The chin sticks out, so to speak, as a distinguishing human trait. As such, experts have numerous theories about the chin's evolutionary purpose. We present the best in Science Smackdown.

The Chin as Biomechanical Brace

The biomechanical view has two camps. Human language arose around the same time as the chin. So one camp argues that the tongue muscles' repetitive action during speech might have led to an extra anchor of bone, which became the chin. The second camp thinks it stems from the mechanical stresses of eating: the masticatory hypothesis.

But earlier this year, anthropologist Nathan Holton and his University of Iowa colleagues published a paper disputing the masticatory hypothesis. They studied chin growth in 37 people between the ages of 3 and around 20, when the chin becomes prominent, and found that bigger chins didn't cause more resistance to chewing forces in the lower jaw. Ignoring the speech argument, they speculate that the chin must play another role — one of the two sketched below, perhaps.

The Come-Hither Chin

Sexual selection argues that the best mates advertise their superior genes with distinctive physical characteristics. And the chin figures prominently in facial attractiveness studies. Females seemingly prefer males with a broad or square chin; conversely, males fancy females with a narrow chin.

If this preference truly has evolutionary roots, it follows that male chins would be broader, on average, than female chins. Indeed, after measuring 180 chins from skeletal samples from around the world, Zaneta Thayer of Northwestern University and Seth Dobson of Dartmouth College established "sexual dimorphism" of chin shape. They, too, criticized the masticatory hypothesis, saying if the chin evolved to aid chewing, it should be the same size in men and women.

The Meaningless Chin

Between the fetal stage and adulthood, facial bones change shape and position. The jaws pull back and the face grows downward, leaving the chin as a sort of island. Harvard's Richard Lewontin, a professor emeritus of evolutionary biology, dismisses all adaptive hypotheses of the chin. It's not evolutionary, he wrote — it's just a residue of two different facial growth fields evolving at different rates.

Timothy Bromage at NYU College of Dentistry agrees, but he says just because the chin didn't evolve for some grand purpose doesn't make it valueless. For one, it helps us maintain an open airway by giving room to the voice box and tongue. What the endless seekers of the meaning of the chin ought to know, he says, is that the chin is a secondary consequence of "the adaptation to stand upright, the reorientation of the face to maintain a horizontal visual field, and the development of our large brains." In other words, the chin is a small moving part in a grand scheme.
—JEFF WHEELWRIGHT

FROM LEFT: APPLE2499/SHUTTERSTOCK; BULIN/SHUTTERSTOCK

DID YOU KNOW? The U.S. Geological Survey in September announced a new official elevation for Denali: 20,310 feet, 10 feet less than the previous official height of 20,320 feet. No, North America's tallest mountain hasn't shrunk. The new elevation was established using GPS technology much more accurate and advanced than the technology used to measure the peak in the 1950s.


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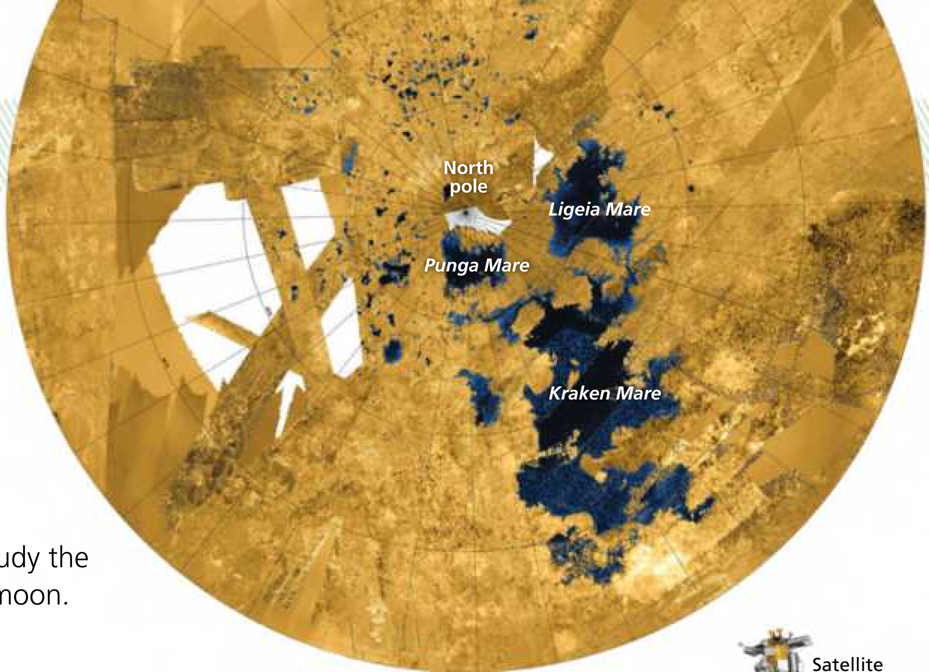
To the Depths of Titan

Astronomers learn how to study the seafloors of Saturn's largest moon.

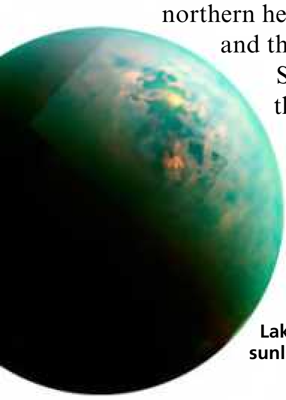


Cassini has explored the lakes of Saturn's moon Titan for more than a decade (above; lakes appear blue-black and land appears yellow to white). The probe can now also measure the depths of some of those seas, thanks to a tweak in analyzing data.

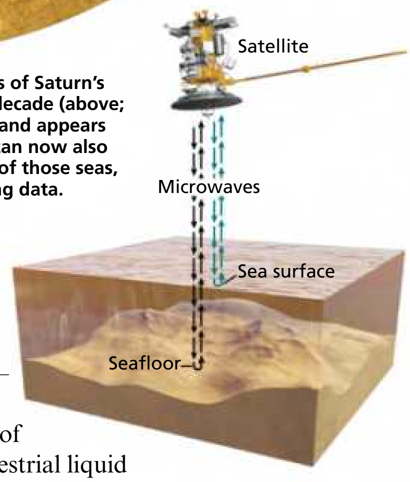
Eleven years into its mission exploring Saturn and its moons, the Cassini spacecraft continues to make new kinds of discoveries. Most recently, it helped researchers map the bottom of the major seas and lakes on Titan, thanks to a new method for analyzing the venerable probe's data.

RADAR, one of Cassini's 12 science instruments, maps the surface of Titan, Saturn's largest moon, when it flies near it by sending down microwaves and timing their return trip. Scientists had assumed Titan's lakes would absorb the microwaves, eliminating any chance of measuring the moon's seafloors. But in May 2013, Cassini passed over Titan's northern hemisphere for another view of the surface, and the sea Ligeia Mare was along the path.

So Marco Mastrogiuseppe, a researcher on the Cassini team who had used instruments like RADAR to map subsurface water on Mars, decided to try something. He fed the Ligeia Mare data into his Mars software, again just assuming the microwave signal would die out as it passed through the lake's mix of liquid ethane-methane.



Lakes around Titan's north pole glint in the sunlight in this mosaic of Cassini images.



Instead, his code revealed two signal peaks: one from the surface's reflection and the other 520 feet deep — the seafloor. "This is the first direct measurement of the depth of an extraterrestrial liquid body," he says.

Testing out their new ability, Mastrogiuseppe and colleagues then analyzed 2014 data of Kraken Mare and 2015 data of Punga Mare, Titan's largest and third-largest seas, respectively. They detected the seafloor at Punga, about 390 feet deep, but nothing at Kraken. It's either too deep (at more than 650 feet), or it's filled with a different, radar-absorbing liquid. Even though Cassini's mission ends in 2017, scientists will continue to scour old data with this new capability. — LIZ KRUESI

Positives Attract

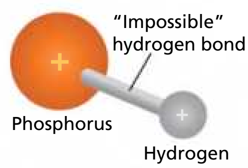
Researchers find a new kind of hydrogen bond.

The saying "opposites attract" certainly applies to hydrogen bonds, which are made of one negatively and one positively charged atom. But chemists at the University of Copenhagen have discovered a new kind of hydrogen bond that, at first glance, should be impossible: It's composed of two positively charged atoms, one phosphorus and one hydrogen.

Hydrogen bonds hold together pairs of molecules in water and DNA, and they help antibodies function. Typically, and logically, a positively charged hydrogen atom bonds to a negatively charged atom of oxygen, nitrogen or fluorine.

But phosphorus is slightly positive. Relying on a technique called infrared spectroscopy to explore the bonds between atoms, the researchers noticed it attaching to positive hydrogen atoms.

In a way, the new bond still follows the old adage. Charge isn't always distributed evenly around an atom. And in this case, the scientists found that the phosphorus had a little patch of negative charge, just enough to hook up with the hydrogen atom.



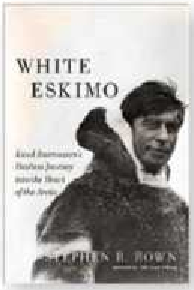
For now, the new bond has only been seen in a lab. But it could play a role in helping scientists understand how proteins fold, a process that's crucial to the most basic structure and function of living organisms. — SHANNON PALUS

FROM TOP: NASA/JPL-CALTECH/ASI/USGS; ROEN KELLY/DISCOVER; NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA/UNIVERSITY OF IDAHO; ALISON MACKEY/DISCOVER

'Tis the season for gift-giving, as well as settling into a cozy spot with a good read and a cup of hot cocoa. That's why books make great presents, for family and close friends, for co-workers and casual acquaintances … and for yourself. We found some pages worth turning for even the most hard-to-please reader on your list.

For Armchair Adventurers

White Eskimo
Knud Rasmussen's Fearless Journey Into the Heart of the Arctic
By Stephen R. Bown

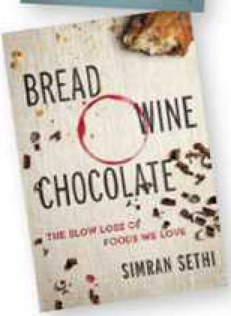


Not as famous as Shackleton or Nansen, Inuit-Danish Rasmussen was arguably even more intrepid, traveling by dog sled from Greenland to Alaska in the 1920s. Bown captures both his charisma and soulful side in a biography full of wonder and peril.

For Foodies

First Bite
How We Learn to Eat
By Bee Wilson

Food writer Wilson probes the psychology of food memories, dips into the chemistry of flavor and digs deep into the physiological and social roots of obesity in this smorgasbord of insights.

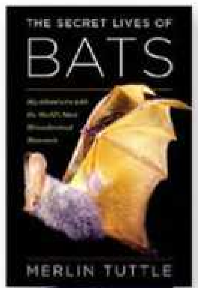


Bread, Wine, Chocolate
The Slow Loss of Foods We Love
By Simran Sethi

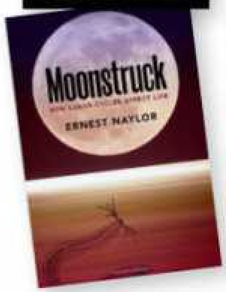
From the industrialization of chocolate to the art of turning grapes into bottles worth triple digits, Sethi tucks into the science, business and culture of our most treasured foods — and why they're at risk of extinction.

For Night Owls

The Secret Lives of Bats
My Adventures With the World's Most Misunderstood Mammals
By Merlin Tuttle



Creatures of the night, what wonderful science they make! Ecologist Tuttle, who has studied bats for more than half a century, reveals their unique intelligence, social hierarchies and necessity for healthy ecosystems.

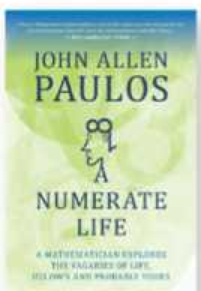


Moonstruck
How Lunar Cycles Affect Life
By Ernest Naylor

From werewolves to lunacy, folktales claim the moon has instigated a long list of odd behaviors. The reality of the moon's influence on life is even more intriguing: It may have been playing a guiding role since evolution's earliest days.

For Number Crunchers

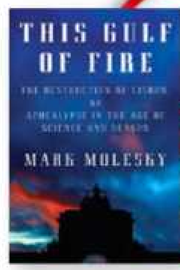
A Numerate Life
A Mathematician Explores the Vagaries of Life, His Own and Probably Yours
By John Allen Paulos



Mathematics is an elegant field, but too often its beauty gets lost in translation for outsiders. Paulos manages to get deep while keeping the tone light by mixing personal anecdotes and asides with key concepts: It's a rumination on numeration.

For History Buffs

This Gulf of Fire
The Destruction of Lisbon, or Apocalypse in the Age of Science and Reason
By Mark Molesky



In 1755, long before global seismograph networks or tsunami warning systems, a powerful earthquake hit Portugal, devastating the cosmopolitan city but also inspiring a new, scientific approach to understanding Earth's shudders.

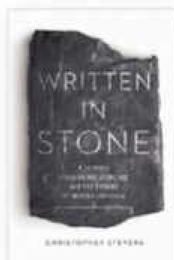
For Star Chasers

Searching for the Oldest Stars
Ancient Relics From the Early Universe
By Anna Frebel

Stellar archaeologist Frebel takes a novel approach to this biography of the young cosmos, building complexity from one chapter to the next, textbook style, but with numerous personal musings. (For more on Frebel's research, see "The Archaeology of Stars," page 38.)

For Anthro-Enthusiasts

Written in Stone
A Journey Through the Stone Age and the Origins of Modern Language
By Christopher Stevens



In what may be one of the more intriguing dictionaries ever assembled, Stevens compiles words at the root of Indo-European languages: a near-global, 6,500-year-old mother tongue that, he argues, remains the basis for everything we speak and write.

— GEMMA TARLACH

Meet the bats that captivated author Merlin Tuttle at DiscoverMagazine.com/Bats

RIBBON: DIDECS/ISTOCK

Storms on Other Worlds

Lightning might last only an instant, but it can shape a planet's atmosphere and even spark life.

BY **SHANNON PALUS**

One of nature's most electrifying light shows, lightning can occur in watery clouds, ashy volcanoes or even extrasolar worlds. Here, the Puyehue-Cordón Caulle volcanic complex in Chile lights up the sky.

On March 5,1979, the Voyager spacecraft hurtled past Jupiter and sent back a grainy snapshot of something previously spotted only on Earth: bursts of lightning. It was proof that our home planet isn't alone in atmospheric spectacle.

But it wasn't surprising. After all, lightning is just a rush of electrons leading to an electric spark on an atmospheric scale — any atmosphere. In the years since, spacecraft have spotted bursts of lightning elsewhere in our solar system, from the cloud tops of Venus, to Saturn's moon Titan, to an electrical storm so big and bright on Saturn itself that it shone even during the day.

Similarly, powerful streams of electricity almost certainly crackle in the skies of thousands of exoplanets strewn throughout the galaxy. But so far, there's no proof. German physicist Christiane Helling of the University of St. Andrews in Scotland wants to spot that extraterrestrial lightning, hundreds of thousands of light-years away. And since we don't yet have faster-than-light travel, she'll do it with increasingly powerful telescopic observations.

That search matters because lightning may come and go in an instant, but its electrical crackling can alter the chemical makeup of the air around it. In fact, the effects of lightning are so great that it might just be a vital ingredient of life itself.

Christiane Helling

STORMY STARTS

Lightning, in all its forms, starts with clouds. So did Helling's research. She's always loved what she calls "small physics," the interactions of particles on a scale too small to see with the naked eye. In 2001, while a postdoc at the Technical University of Berlin, she developed a computer model called Drift. The name refers to the way microscopic particles ebb and flow within a cloud, pulled around by gravity. She didn't know it at first, but this research was the perfect setup for a burgeoning lightning researcher.

Helling used the model to simulate how dust whirls and swirls around in the atmospheres of brown dwarfs: gassy bodies too big and warm to be planets, but too small and cool to be stars. By studying the light from these "failed stars," astronomers can learn what they're made of. So far, they've found many familiar molecules like oxygen and carbon dioxide, as well as minerals like silicates and iron.

Using Drift, Helling found that these molecules can form what she calls "gemstone clouds" since the silicates and metals that comprise them most likely make them appear glittery and colorful. In the clouds in her model, atmospheric gas would sometimes condense onto the shimmering dust particles, increasing in size to a few millimeters big. That's where the possibilities get interesting, because these particles often collide, producing a charge, the makings of lightning.

Here on Earth, our storm clouds are made of charged water droplets and hailstones. But water is not essential for lightning; it's just the medium that carries around electrons. In fact, small lightning storms often occur in volcano dust. As ash swirls around in the aftermath of a violent eruption, it, too, can become charged.

That sets the stage for lightning. The different charges within the cloud — whether spawned from gemstones, water or ash — create an electric field. Any free electrons would rush, attracted, to the positive side, akin to a ball falling through Earth's gravitational field. Get enough electrons colliding and "falling," and boom — you've got lightning.

ELECTRIC MAYHEM

Helling showed that the glittery clouds on brown dwarfs can create

TOP: FRANCISCO NEGRONI. BOTTOM: UNIVERSITY OF ST. ANDREWS

such charges. Then, in 2009, she wondered if these dusty clouds might be the foundation for strange alien lightning storms.

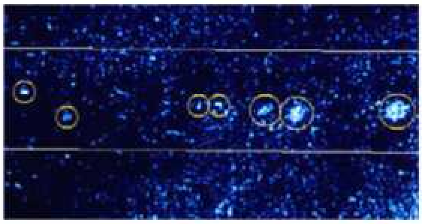
That same year, astronomers began finding multitudes of planets beyond our solar system. Exoplanets and brown dwarfs are different in many ways, but for Helling's purposes — clouds and what can happen inside them — they are quite similar. And while both types of worlds are not directly visible from Earth, researchers can determine the chemical makeup of their atmospheres with today's telescopes. Using that data, Drift revealed that gaseous exoplanet atmospheres were just right for giving rise to glittery gemstone clouds, too.

At the University of St. Andrews, Helling started a research group named Life, Electricity, Atmosphere, Planets (LEAP). The goal: to find out if lightning exists in these new worlds, and pave the way for others to discover just what the implications might be.

Figuring out how a burst of lightning begins in the first place amid swirls of dust was key to Helling's computer models. Luckily, analogs of extrasolar clouds exist here on Earth. "The exciting thing is [their] composition is similar to what we know of volcanoes," says Helling.

In 2013, Corrado Cimarelli, a volcanologist at the LMU University of Munich, re-created volcanic lightning in his lab by pushing dust into a small glass tube at extremely high pressure. He took slow-motion footage, elucidating the small physics of the lab-made lightning. What flashed on the screen was a spray of black grains, released from a pressurized tube like water from a fire hose, with little bursts of electricity — veins of white just centimeters long.

Adding laboratory data like this to Drift, Helling found that lightning could happen on both gaseous exoplanets and brown dwarfs — in bolts as large as the Empire State Building. Cimarelli's lab-made lightning, using the same kinds



Likely lightning strikes dot Jupiter's surface in this 1996 photo, which also shows latitude lines 43 and 46 degrees north.

Stanley Miller (above), along with Harold Urey, showed in a 1950s experiment that electricity might be a key component for establishing life.

of materials as the gemstone clouds, suggests that streamers are most likely to occur when dust is pelted together quickly. This suggests that lightning might be most likely on planets with plenty of light and radiation from a host star to create wind.

ATMOSPHERES OF ELECTRICITY

With gemstone clouds — and their attendant lightning — more common than she could have imagined, Helling knew for certain that alien lightning could flash in atmospheres all across our universe. But how could she ever tell? These worlds are too far away to see directly. It's not simply a matter of sending a space probe or pointing Hubble toward the nearest exoplanet.

To figure out how to look for actual proof of extrasolar lightning, Helling combined Drift's code with another atmospheric model called Phoenix, created by astrophysicists at the University of Hamburg. Phoenix placed the individual clouds that Drift could model into the context of a whole planet. Using results from Drift-Phoenix, Helling made the first steps toward figuring out exactly what telltale elements lightning would leave behind in a world's atmosphere. It turns out that where there is lightning — whether on Earth or worlds away — there is slightly more methane and carbon monoxide.

Today's observatories capture just the big features of an atmosphere; they aren't yet sensitive enough to pick up the trace amounts of the chemicals lightning would leave behind on other worlds. Fortunately, more powerful views of exoplanets are on the horizon when the James Webb Space Telescope launches in 2018. The unparalleled view it will provide to astronomers could include a glimpse of a stormy world. But that's not all that finding lightning's signature would mean.

More strikingly, lightning may also be a key catalyst for spawning life. An experiment by biochemists Stanley Miller and Harold Urey over 60 years ago established that, if you take the wet, disorganized ingredients found on early Earth — water, ammonia, methane, hydrogen — and add an electric spark, you get amino acids, the building blocks of all known life.

That doesn't mean that lightning equals life. Far from it. Liquids are rare, and astrobiologists think that gaseous planets, the kind that Helling has studied so far, aren't as likely to harbor life as Earth-like rocky ones. But habitable planets are a tantalizing prospect, one that Helling references in the very name of her LEAP project. In the search for life, lightning could be a key clue.

We might not ever be able to see extraterrestrial lightning firsthand. But how electrifying to know that where there's lightning, there just might be something to stare back up at it. D

Shannon Palus *is a freelance writer based in Brooklyn, which is not the best place to view a lightning storm.*

FROM TOP: NASA/JPL; UC SAN DIEGO

Lather, Rinse, Repeat

A 40-year-old demands to stay at the hospital, yet nothing seems wrong — until he explains why he can't go home.

BY **DOUGLAS G. ADLER**

Twenty years ago I was a resident in psychiatry and was called down to the emergency room one night to see a patient. Richard, 40, was wearing jeans, a button-down shirt and exceptionally clean white sneakers. He had neatly folded his unused patient gown and placed it at the foot of the bed. He was calm and didn't appear to be physically injured. His pulse-oximeter, clipped around his right index finger, displayed normal vital signs on the bedside monitor.

I glanced back over my shoulder to the senior emergency room physician sitting at the desk, nodded toward the patient and gave him a quizzical look. The other doctor raised an index finger and circled it around his right ear — the universal "crazy" gesture.

I walked over to Richard and introduced myself. "What brings you here tonight?"

"Well, it's a little hard to explain, but … I have nowhere else to go," he said.

It's a line I had heard many times before. When a patient tells you they have nowhere else to go, it often suggests some sort of psychosocial crisis. Maybe they are homeless, have drug withdrawal symptoms or just escaped a fight with their spouse. I didn't smell alcohol on Richard's breath, and he didn't seem to be under the effects of any drugs, or to be withdrawing.

"Did someone hurt you?" I asked.

"No."

"Are you afraid of someone or something outside of the hospital?"

"No, not at all," he said, shaking his head.

Now I was a little perplexed. "Is there something here in the hospital that you need?"

"Just a bed."

"Why not go to a hotel?" I asked.

"I don't have any money on me," he explained.

"Do you need medicine?" I probed.

"None that I can think of."

Richard was not an ordinary patient in the psych ER. He clearly had a motive for coming in that he was reluctant to share with me. Was he embarrassed about something? Afraid? Ashamed?

"Look," I said, "most people don't show up here in the middle of the night asking to be admitted without a pretty good reason. Can you tell me more about what is happening?"

COMING CLEAN

Richard got up from the gurney, straightened his shirt and removed the pulse-oximeter. He walked to the sink and carefully washed his hands, one finger at a time, paying extra attention, I noticed, to the finger that was attached to the monitor. He turned to me and, in a half-whisper, said, "I have nowhere else to go because I finally … I finally got my apartment clean."

I must have looked puzzled. Richard sighed and said, as if he were explaining something to a child, "I can't go home because my apartment is finally as clean as it needs to be."

A light bulb went on. I started nodding. Using some of his own words, I asked Richard, "How long have you been trying to get your apartment as clean as it needs to be?"

He looked at me and saw understanding in my eyes. "Four years."

Now I was certain. Richard had obsessive-compulsive disorder, or OCD. People sometimes casually joke that they or someone else has OCD if they are a "neat freak," but real OCD is no laughing matter. As the name suggests, people with OCD have both obsessions (intrusive and unwanted thoughts that produce anxiety, fear or dread) and compulsions (repetitive behaviors designed to try to reduce the intensity or severity of obsessions).

Patients may have different symptoms: repetitive counting, intense hand-washing (often to the point of rubbing the skin raw) or excessive cleaning. Some OCD behaviors can make sense to someone who does not have the disease (compulsive hand-washing to get rid of germs), whereas other behaviors make sense only to the patient (spending an hour walking back and forth through a single doorway in an attempt to "get it right").

Even though I had been with Richard

DIGITAL GENETICS/SHUTTERSTOCK

for just a few minutes, the puzzle pieces were falling into place: his too-clean sneakers, his failure to put on the hospital gown (not clean enough for him), his hand-washing ritual with special attention to where the monitor had touched his finger and, of course, his remark of finally having cleaned his apartment to his satisfaction.

"It's just a two-bedroom apartment," he said. "It shouldn't be so hard to clean, but it is. I try cleaning just one room at a time, but something always happened to mess it up. Sometimes I spend my entire weekend just cleaning and never even leave the apartment, but I could never get it clean enough. Today was different. I started early this morning and worked all through the day. Room by room, I knew I was finally getting it right — I couldn't believe it! Eventually, I found myself standing in the hallway and cleaning the outside doorknob on the front door to the apartment. With a sudden clarity, I realized the apartment was perfectly clean, so I just pulled the door shut to lock it all in. The door locks automatically. I have my keys in my pocket, but my wallet was in a drawer inside. I stood there for a while and thought about things, and then I came here."

"You know what this is, right?" I asked him.

"Yes, yes," he said, "I know. I've read all about it. I know I have OCD."

"Have you ever seen a doctor about this before?" I asked.

"No," he said.

At the time, I was still under the supervision of more experienced senior doctors. I excused myself and called the on-call supervising psychiatrist, and I explained the situation to him. He suggested, to my surprise, that I send the patient home.

"But he has untreated OCD," I said. "It's ruining his life."

I could tell he was getting annoyed. "Send him home," he said.

"But …" I said.

"I'm not admitting someone to the hospital just because they cleaned their apartment!" he barked, and hung up.

A RATIONAL SOLUTION

Now I was in a bind. As a resident, I could not admit the patient to the hospital over the objection of the senior physician. Part of me also saw his point — maybe Richard was troubled, but not enough to warrant admission to the hospital. Yet, I also knew Richard needed help.

I went back into his room, and we talked some more. He told me the OCD behaviors started when he was a child and had progressively worsened. He lost several jobs because of it. He once was fired for being late to work — because he spent three hours trying to get his car to line up perfectly with the yellow stripes of his assigned parking space.

Richard had read about OCD and had some insight about his situation, though not enough to help him. I asked him if he would be willing to see a psychiatrist, and he agreed to do so while he was in the hospital.

When I told him he couldn't stay, he was crestfallen.

"If I go home, I will mess up how clean it is, and I will never get it this clean again!"

"Even if I did admit you, you couldn't stay here forever. You'd have to go home eventually."

"I could get another apartment!" he said. I shook my head at him.

"But," I said, "Your wallet and clothes are home. You need to go home. I will make you an appointment to see one of our psychiatrists as an outpatient."

"No!" he told me. "I'm OK. I can deal with it."

"You're not OK. This is a big problem. This has cost you jobs," I said.

At this, he became defensive. "I had to park my car right, or else I wouldn't have been able to get any work done that day!"

"They won't let me admit you to the hospital," I said firmly.

"I have to stay here. I can't go home!" He was shouting now. "It's perfect! It's finally perfect!"

A heavy silence fell over the room. We both just sat there.

"What about dust?"

Richard froze and gave me a look, startled and quizzical at the same time. "Dust?"

"Yes, yes," I said, realizing I got my foot in the door. "Dust. Dust will settle even in the cleanest of apartments. Eventually, dust will settle, and it will not be perfectly clean. You have to go home and clean up the dust, which means you *can* go home again."

Shocked, Richard put his hands to his face. "You're right! Dust!"

By appealing to the rational part of his brain, the behavior that drove him to the ER in the first place would now get him home. I called him the next day to set up his outpatient psychiatry appointment. He agreed to come to our clinic to take the first step in getting the help he needed. D

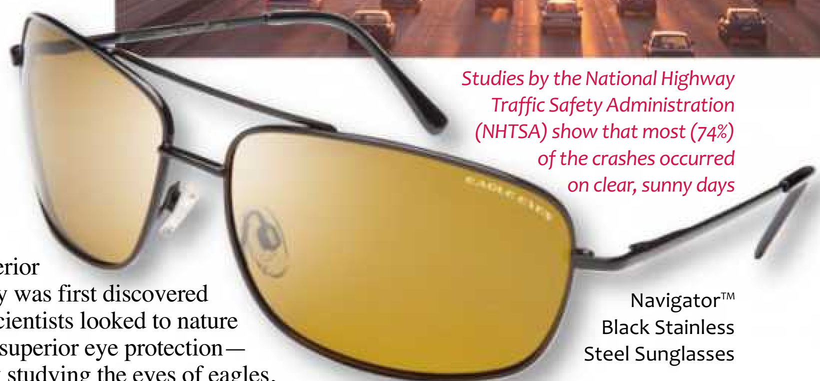
__Douglas G. Adler__ is a professor of medicine at the University of Utah School of Medicine in Salt Lake City. The cases described in Vital Signs are real, but names and certain details have been changed.

MARIE BLUM/MASTERFILE/CORBIS

Urgent: Special Driving Notice

To some, sunglasses are a fashion accessory…

But When Driving, These Sunglasses May Save Your Life!



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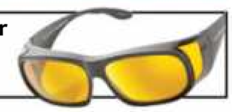

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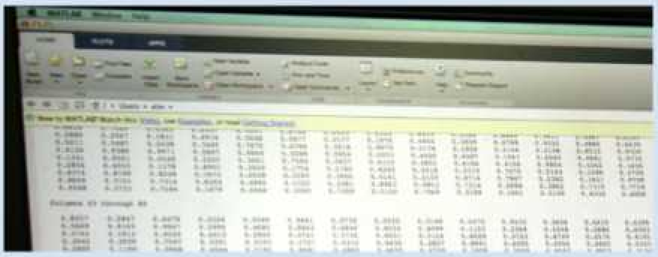
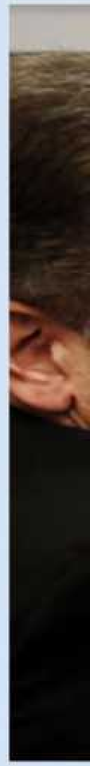
A New York Police Department camera hangs over Times Square in Manhattan. Local and federal agencies use facial recognition technology to help solve crimes.

Face Time

From catching crooks to tagging friends, facial recognition software is watching **you**.

BY **MICHAEL FITZGERALD**
PHOTOS BY **YANA PASKOVA**





Above: Screens show the NYPD facial recognition unit's active cases in New York and along the East Coast.

Left: Strings of numbers represent a face in facial recognition software.

BOTTOM LEFT: MICHAEL FITZGERALD

IT WAS JUST AFTER MIDNIGHT IN NEW YORK WHEN POLICE CHASED DOWN AND ARRESTED the suspect wanted in a potential hate crime. A gay man had been shot and killed with a silver revolver. The suspect was cooperative to a point. He gave them the silver revolver in his holster. He also gave them an ID.

Then he clammed up. When they brought him to the precinct to book him, the ID turned out to be fake. He wouldn't tell them his real name. They couldn't take his fingerprints.

By this time, it was just after 7 a.m. The officers called Edwin Coello, the sergeant who has led the New York Police Department's Facial Identification Section since it was formed in late 2011. It was a Saturday, and Coello was still in his robe at home, but he pulled up a scan of the ID on his laptop and started working.

A guy cracking a case in his bathrobe sounds like something out of a cop show. On TV, police officers use technology as a kind of magic detective's aid, pumping out important clues on demand. In the office, on a normal day, watching actual police detectives use actual technology on actual cases presents a more complicated picture. "It's far from *The Bourne Supremacy*," Coello says.

In the unit's office on the ninth floor of One Police Plaza, a Brutalist monolith in south Manhattan, banks of 55-inch LED monitors hang from the wall, an ever-changing art gallery of cases. But most of the work happens in the detectives' cubicles, clustered in the middle of the room.

Each has three monitors. A detective uses a mouse to rotate a face on her screen to the same full-frontal angle as a mug shot. The photo is distorted, taken from a security camera with a fish-eye lens. She'll try it this way against the arrest database, but if she gets no matches, she will begin to adjust the fish-eye ratios so the person's face will have normal proportions, hoping for clues to an identity. Another detective captures a frame from a cell phone video from a crime scene. He'll also run that through the mug shot database. One screen shows a wire-frame rendering of a face in 3-D; that detective is working to build out a full facial image based on a profile view.

WHAT'S IN A FACE?

With most facial recognition technology, faces don't look like faces at all. Instead, streams of numbers represent hairlines, eyebrows, nose structure, jaw lines, ears, scars or moles, as well as the head's pitch, yaw and roll (head angle, whether the chin is up or down, and how far off-center the face is). The NYPD's software accounts for more than two dozen factors in all. Algorithms, or recipes for how computers solve a problem, use the numbers to try to determine whose face it is. A simple change of expression can throw off the numbers in ways that create real problems for an algorithm.

It can take hours or even days to prepare a photo for comparison against a database. But on that Saturday morning working from home, Coello had a straight-on photo with a neutral expression in poor lighting. "I had to enhance it because the image was a little blotchy," he says.

After a couple of minutes, Coello asked the investigator, "Can you just take a look at him and tell me: Does he have a scar or mark on his face?" There were no marks on the face in the ID, but there was a scar on one of several hundred faces the database offered as a match. The investigator said the suspect has a scar. Coello told the detectives that a possible match is Elliot Morales, who had been arrested six times, once on suspicion of attempted murder. The work took about an hour, and Coello was back to hanging out with his kids on a Saturday.

More and more, we're seeing facial recognition technology emerge as part of crime-fighting, as police departments hear about successes like those in New York. Outside of New York, such as Pinellas County, Fla., where the software has been used for 14 years, it's helped capture criminals with outstanding warrants during routine

NYPD Det. Roger Rodriguez shows how a simple photo from a security camera was enhanced with facial recognition software to rotate and create a straight-on image. It then matched with a person in the database. In this case from 2013, the man was eventually sentenced on burglary charges.

traffic stops.

The NYPD has used facial recognition technology in more than 8,000 cases, and it found 2,000 possible matches in its arrest database. Of those, more than 1,000 led to arrests. One notable case in 2012 involved a shooting at a barbershop, where a man fired a shotgun at an acquaintance getting a haircut. The victim and other witnesses knew the man only as "Armani," but one of them had Armani's picture on his Facebook page. Police used that photo to look for a match in their database, found one, and made the arrest.

Facial recognition software is becoming common in motor vehicle registries, too, as more than three dozen states use the technology to look for fake driver's licenses and identify people during investigations.

At the federal level, the Diplomatic Security Service, a unit of the State Department, used a newly installed facial recognition system in 2014 to find Neil Stammer, who skipped bail in 2000 on charges including sex with a male minor. The agency was testing the system by running it against the latest FBI wanted posters; by happenstance, Stammer's mug appeared on one of them. He'd been living under an assumed name in Nepal, where he left a trail by regularly renewing his tourist visa.

In September 2014, the FBI unveiled Next Generation Identification, a database expected to have 52 million records in it, created by merging multiple criminal and civil photo and fingerprint databases from the U.S. and abroad, all in the name of fighting crime and terrorism.

BIG BROTHER, AND SIBLINGS

All this facial recognition technology in the hands of government raises unavoidable questions about Big Brother-like powers. Only it could be even more pervasive than Orwell imagined. There are surveillance cameras all over the place in major cities. "The risk is that the government can track people as they move from place to place," says Jennifer Lynch, senior staff attorney at the Electronic Frontier Foundation. It hasn't happened yet as far as civil liberties advocates can determine from public legal records, but there are no specific rules or regulations against it, she says.

And Big Brother might have siblings. Retailers are already using facial recognition systems to target shoplifters if they hit a store, or chain of stores, more than once. That's similar to how casinos use the technology to identify known card counters, whom security guards can then remove. Some bars used a mobile phone app (before the developer went out of business) that scanned people's faces as they entered. The app determined if bar-goers were male or female, their relative age, and reported the ratio to app users deciding where to head out for the night.

The NYPD cites, repeatedly and without irony, concern for civil liberties as a reason why it only uses the mug shots in its arrest database to look for suspects. But some law enforcement agencies also link to driver's license databases in their states, and the FBI's new database is open to state and local law enforcement.

There has not yet been a prominent case of misidentification, or false

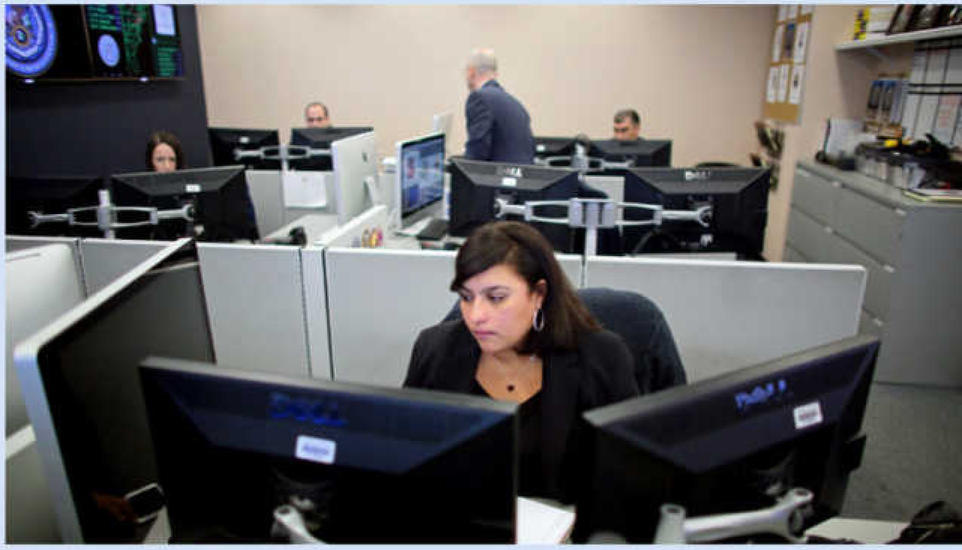
positive, using a facial recognition system. But give it time; issues still occur with fingerprinting, a much older and generally more accurate form of identification than facial recognition, which is sometimes called "faceprinting." After the 2004 Madrid train bombings, the FBI linked Brandon Mayfield, an American attorney, to the bombings through a fingerprint match that proved inaccurate. He spent two weeks in prison and later won a $2 million court settlement and a formal apology from the FBI.

Coello stresses that New York police do not use facial recognition matches as conclusive evidence to arrest someone. "It's only a lead for detectives," he says. "We point them in the right direction." The people who work in facial recognition are all detectives, and they do legwork beyond the photos, conducting detailed searches of a possible suspect's background, like their address, to aid the investigation. "No one is going to go four towns over to hold up a liquor store," Coello says.

Even with clear matches, though, the facial recognition team says the person is only a possible suspect. The department says it has misidentified someone via the technology just five times, most recently in March 2012.

"It's just a tool. It's not DNA, and it's not fingerprints," says Stephen Capasso, the former commanding officer of New York City's Real Time Crime Center, which includes the facial recognition unit. Still, "I think our usage of facial recognition is going to be increasing."

Most of us encounter facial recognition in perfectly law-abiding modes, like photo tags on Facebook and on photo apps like Google Photos, where software algorithms parse our pictures and suggest names for the people in them. Facebook launched its photo-tagging tool in late 2010, and it's become a routine feature for many users. This is certainly the first mass consumer use of facial recognition. It likely won't be the last.



Detectives at work in the NYPD's facial recognition unit in Manhattan. The software allows detectives to enhance poorer-quality photos grabbed from security cameras or videos.

HOW WE GOT HERE

Travelers, for instance, might encounter facial recognition algorithms at airports. In Australia at the end of 2013, P. Jonathon Phillips walked through SmartGate, an automated border control system being used in Australia's eight major international airports to speed customs processing for people from eight countries, including the U.S.

Phillips put his passport in the kiosk and looked at a camera, which automatically matched his face with the image on the passport. He was through SmartGate in five minutes. He knew about the system, but still, "I was amazed when I saw this!" he says. "I've been in the facial recognition field for 23 years. We started out with 'can you recognize?' algorithms. When you go someplace and it actually happens …"

Phillips is arguably the most influential scientist in facial recognition. He started his work in 1993, launching the FERET (Face Recognition Technology) program for the Army Research Laboratory, the first such program. Back then, they were testing algorithms against a database of about 1,200 faces, mostly college student volunteers from George Mason University. He's now an electronic engineer at the National Institute of Standards and Technology, and he manages NIST's facial recognition challenges.

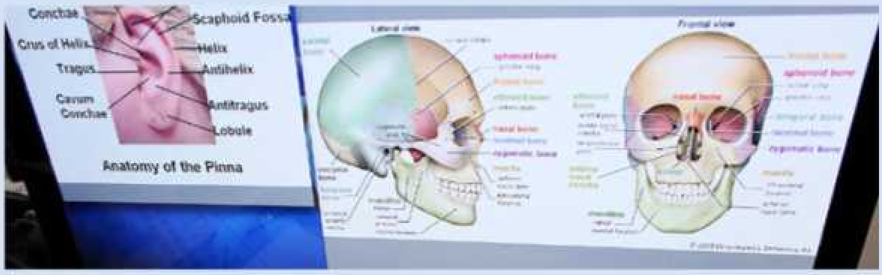
When he started, verifying passport photos presented a difficult problem. Now, many facial recognition algorithms are better than humans when it comes to recognizing a person looking straight ahead under good lighting conditions.

Facial recognition algorithms don't "see" anything, of course. Faces and their features are broken down into strings of numbers representing individual pixels, their colors and their place on what will mathematically correspond to a face. Algorithms must first find a face, and then find the eyes and other features that human brains take in at once. One early technique came via a linear algebra representation called eigenvectors, which let researchers compare similar objects as long as they are precisely aligned. Think driver's license and passport photos, or mug shots, which feature a face looking straight ahead. Researchers used these techniques to create eigenfaces, which to human eyes look ghostlike, but they give algorithms a reference representation of a face to compare with a new face.

It helps the technology that faces are relatively straightforward to analyze. Eyes and mouths are in the same places consistently, and face shapes don't vary much — you'll never find someone with a face shaped like a square, star or a hexagon. By the mid-1990s, facial recognition was a hot technology, and several startups formed to commercialize it.

"That was just fun, the first stage of a new technology sprouting up,"

Above: Det. Rodriguez demonstrates how software builds a model from a security camera photo of him. Using reference points on his face, a computer creates a 3-D model with polygons to place the marked points on a head shape. The photo of Rodriguez's face is draped over the polygon model, creating a 3-D version of a potential suspect. The image can then be rotated to compare it with faces from police mug shots or online snapshots.



Right: An old-school chart at the NYPD facial recognition unit shows the anatomical features of the human head.

says Brian Martin, senior director of research and technology at MorphoTrust, the dominant provider of facial recognition software to government and law enforcement. In 1998, he received a Ph.D. in condensed matter physics from the University of Pittsburgh. A year earlier, he started working at Visionics, an early facial recognition startup. Its first product? A biometric screen saver that used your face as your computer password. Martin says it had two big selling points: You didn't have to remember your password, and it would take pictures of anyone who tried to break into your computer. But that day's low-resolution cameras meant the technology was especially prone to issues with image quality.

Martin says accuracy improved when researchers started to use what's called local feature, in which algorithms don't just use the whole face, but also patches of it, like the shape of eyebrows and the width of the nose. That makes the software less prone to stumbling over expression changes. Around 2005, researchers began applying machine learning techniques to their algorithms, to train them to learn how to match sets of features more and more accurately.

> FACEBOOK launched its photo-tagging tool in late 2010, and it's become a routine feature for most users. This is the FIRST MASS CONSUMER USE of facial recognition. It likely won't be the last.

Today the big push is in "deep learning" — building artificial intelligence algorithms inspired by the brain's neural connections. Our neurons connect to each other through trillions of synapses, which are like nodes on a computer network. These form individual connections influenced by the number of times each neuron communicates with another neuron. Neural networks also consist of connections adjusted by exposure, in effect learning from developing patterns. In facial recognition, these patterns emerge after being "shown" thousands upon thousands of photos. The algorithms mathematically recognize when a face shares enough characteristics to likely be the same as a face in different lighting or with a different expression. Neural network theory isn't much different than it was in the 1990s, but this century's explosion in cheap computing power and availability of data lets researchers take full advantage of the theories.

Once they've trained their algorithms, researchers often test them against publicly available benchmarks. The most popular is a database of images gathered by Erik Learned-Miller, a computer scientist at the University of Massachusetts Amherst, and his colleagues. In 2003, Learned-Miller was a postdoctoral researcher at the University of California, Berkeley, working with a database called Faces in the Wild, developed by David Forsyth, Tamara Berg and others. They pulled tens of thousands of different faces from Web-based news sites ("the wild") to train a facial recognition algorithm they were working on.

The goal was to train the algorithm to automatically label the people in the photos. After a paper on the algorithm was published in 2004, Learned-Miller began getting requests from facial recognition researchers who wanted access to the database for their own work. In 2007, he and a colleague cleaned up the database, getting rid of duplicates and miscaptioned photos, and released it as "Labeled Faces in the Wild," with 13,233 different photos of 5,749 people. The timing was excellent — facial recognition algorithms were getting good at identifying faces in controlled environments, such as passport photos. Researchers wanted something more challenging, and this database fit the bill.

It has since been cited in more than 1,100 papers. In the past eight years, more than 60 research groups have sent the results of their algorithms against

the benchmark for Learned-Miller to post on the Labeled Faces site. Facebook's DeepFace algorithm had the best performance for a brief period last year, only to be passed by a Chinese company, Megvii, whose Face++ algorithm hit 99.5 percent accuracy.

FACING THE FUTURE

Those kinds of numbers suggest Labeled Faces in the Wild has been tamed. Learned-Miller says it's time for facial recognition researchers to move on to new problems. There are still plenty of those. Computers have a hard time recognizing faces in less-than-ideal lighting conditions, or when analyzing faces at more than a 40-degree angle from straight on.

Failure rates can run as high as 2 in 10 for everyday "point and shoot" photos, according to Phillips, compared with 1 in 1,000 for mug shots. NIST's current facial recognition project, dubbed Point-and-Shoot Face Recognition Challenge (PaSC), involves a dataset of 9,376 still images and 2,802 videos. Labeled Faces in the Wild uses photos of well-known people taken by professional photographers. The PaSC, launched in October 2013, focuses on the rest of the world's photos: those taken on cell phones or simple digital cameras. These can be poorly staged and blurry.

At its core, facial recognition is an artificial intelligence challenge, albeit one that is becoming less challenging. Phillips says knowing how humans recognize faces in these conditions will help develop the algorithms. Most algorithms focus on the center of the face where humans use lots of different cues about a person, like the part of their hair. We are better — after spending a morning with someone, most of us will recognize that person's face consistently, in most lighting conditions, at most angles. The algorithms need intensive training, the deep learning that takes advantage of computational speed and pattern-matching.

Some researchers, like Learned-Miller, have tried very different approaches. When I visited his lab at UMass Amherst, his current tool was, oddly, an old-fashioned world globe. The globe was not quirk, but work — it was a stand-in for a human head. He was working on an algorithm that could recognize the rotation and position of the globe. This could help make algorithms better at recognizing the pose of a head, for example: Is it straight on, or in profile? His approach would be called unsupervised learning. (Feeding the algorithm many pictures of faces in different poses would be called supervised learning.)

On the day of my visit, Learned-Miller and then-grad student Cheni Chadowitz looked through data generated by the algorithm, written in the computer program MATLAB.

At its core, facial recognition is an ARTIFICIAL INTELLIGENCE CHALLENGE, albeit one that is becoming less challenging.

Chadowitz had adapted an earlier algorithm written by Learned-Miller that only recognized faces in images that showed them straight on. Learned-Miller stared at a scatter plot, which showed the improved algorithm was having some success at taking different images of a geographic feature, like the Horn of Africa, and putting it at the correct latitude and longitude.

The globe project was temporarily put on hold after Chadowitz graduated, but Learned-Miller says he's waiting for the right student to continue working on it. For now, Learned-Miller is focusing on solving the problem of making facial representations that don't take up a huge amount of memory. He's working on an algorithm that combines many images into a "mental model" that captures all the information about a face that a video might, but is much smaller.

While Learned-Miller's basic research may not impact the market for 10 years or more, other researchers work on a shorter timeline. "A lot of people in computer vision are really excited about building things that work, and it's difficult to build things that work well," he says. "Often we'll build something that works 90 percent of the time, but if you put it out in the world and it fails one out of 10 times, in the consumer world, that's unacceptable."

PUTTING ON THEIR WORK FACE

While facial recognition companies have emerged in the past, only to fail or struggle, the time seems ripe for commercialization. It's a nearly $3 billion business, led by companies like MorphoTrust, NEC and Cognitec, which see their biggest sales from government and corporate security. But the market is expected to double by 2020.

Some of that growth will come from expansion in traditional markets as

Above: P. Jonathon Phillips is considered the most influential scientist in facial recognition.

Left: The NYPD posts signs when an entire area is under video surveillance, such as the base of the Brooklyn Bridge.

Right: Computer scientist Erik Learned-Miller of the University of Massachusetts Amherst used a globe to work on an algorithm that could recognize its rotation and position.

more law enforcement agencies adopt the technology. New kinds of consumer applications are also emerging. Facial recognition software can be used for other things besides identifying people. It's also used to search for images of people with certain features or to track head movement and facial expression. Megvii's Face++ is being used in China by dating services and even for playing video games. Companies are using a facial recognition programming interface from Kairos, a Miami-based provider of a facial recognition interface, for things like time management software, health care management and in amusement parks that want to sell photos to visitors.

There is also a move to blend facial recognition with a technology called facial analysis, which uses a person's facial expression to predict mood and even diagnose certain illnesses.

Such applications raise substantial privacy concerns: Imagine insurers setting rates based on what your photo suggests about your health. The Electronic Frontier Foundation's Lynch, pointing to people suspected of shoplifting, says no rules exist to prevent companies from sharing information. "If you shoplift and you're caught by security guards, the store has the right to exclude you," she notes. "But there is the potential for this to trail you from store to store." That already happens in the casino business.

Our privacy laws are also built around our own efforts at self-protection. The Do Not Call Registry, for instance, kicks in only if you register your number in an official database. Facial recognition is different — cameras, often installed by police departments, constantly record us just for walking down a public street.

"Real taxpayer money is being spent to allow law enforcement to point a camera at protesters and be able to identify them by name," says Alvaro Bedoya, executive director of Georgetown Law's Center on Privacy and Technology. "We need to think about whether that's a world we want."

The flip side of this comes from Sgt. Coello of the NYPD. He says facial recognition is terrifically helpful, in practical ways. Detectives used to have to go door to door with an image trying to find out if someone knew the person in the photo. "We don't need to do that now," he says. "You get us the photo, we'll do the rest [in the database]."

Bedoya acknowledges there are specific ways in which the technology could benefit the public. But he worries that it might inhibit public demonstrations, or let strangers and companies snap a photo of us and learn our names, occupations and addresses. An app called NameTag can already do some of this. Its maker, Las Vegas software developer FacialNetwork.com, last year launched an app called CreepShield tied to databases containing photos of half a million registered sex offenders. In June, Bedoya and eight other consumer advocates walked out of discussions on privacy guidelines led by the National Telecommunications and Information Administration, part of the Department of Commerce, citing lack of incentive for businesses to give people the right to consent to having their faces recognized.

There have been no court cases involving the civil liberties impact of facial recognition, partly because we don't yet have evidence that the government or companies are misusing the technology. Texas and Illinois are the only states that have passed laws regulating commercial use of facial recognition. Facebook was sued in April for violating privacy restrictions in Illinois' law; if that case makes it to trial, it will set a precedent.

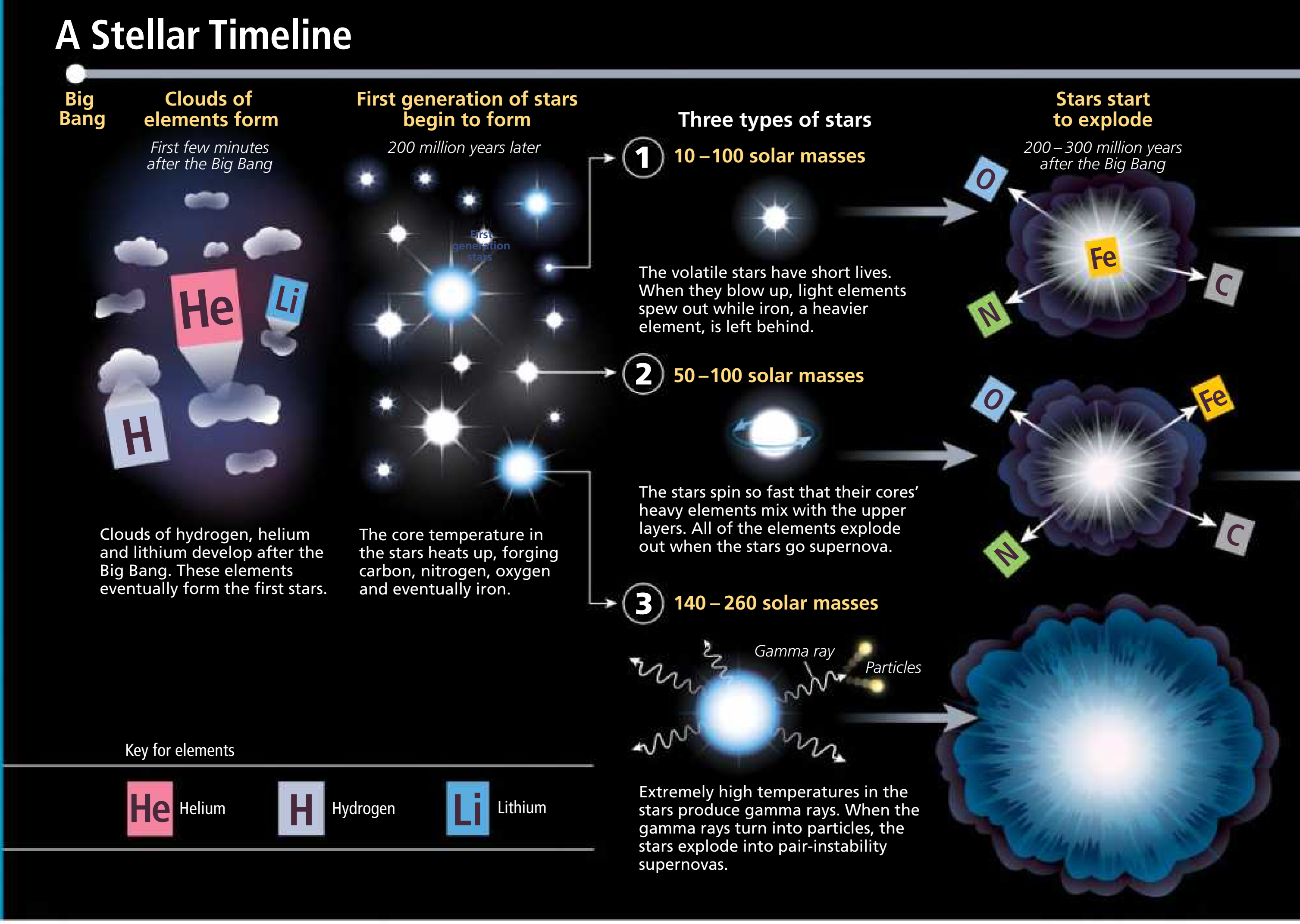
Technologies are famously neutral; it's people who decide whether to use them for good or ill. With facial recognition poised to become a far more widespread tool, we have a choice to make about how and when to blindfold it. D

***Michael Fitzgerald** writes for* The Economist, MIT Technology Review, *the* Wall Street Journal *and many other publications.*

THE ARCHAEOLOGY OF STARS

Some astronomers seek to understand the origins of our universe by reconstructing the lives of its oldest sources of light.

BY **MICHAEL D. LEMONICK**
ILLUSTRATIONS BY **ROEN KELLY**



Archaeologists and astronomers don't seem to have much in common. One digs into the earth while the other looks at the sky, and a stone tool once wielded by *Homo erectus* couldn't be more different from an exploding star at the edge of the visible universe. But the sciences are actually fundamentally similar: Both try to understand the present by looking deep into the past, whether it's the origin of the human species or of the universe.

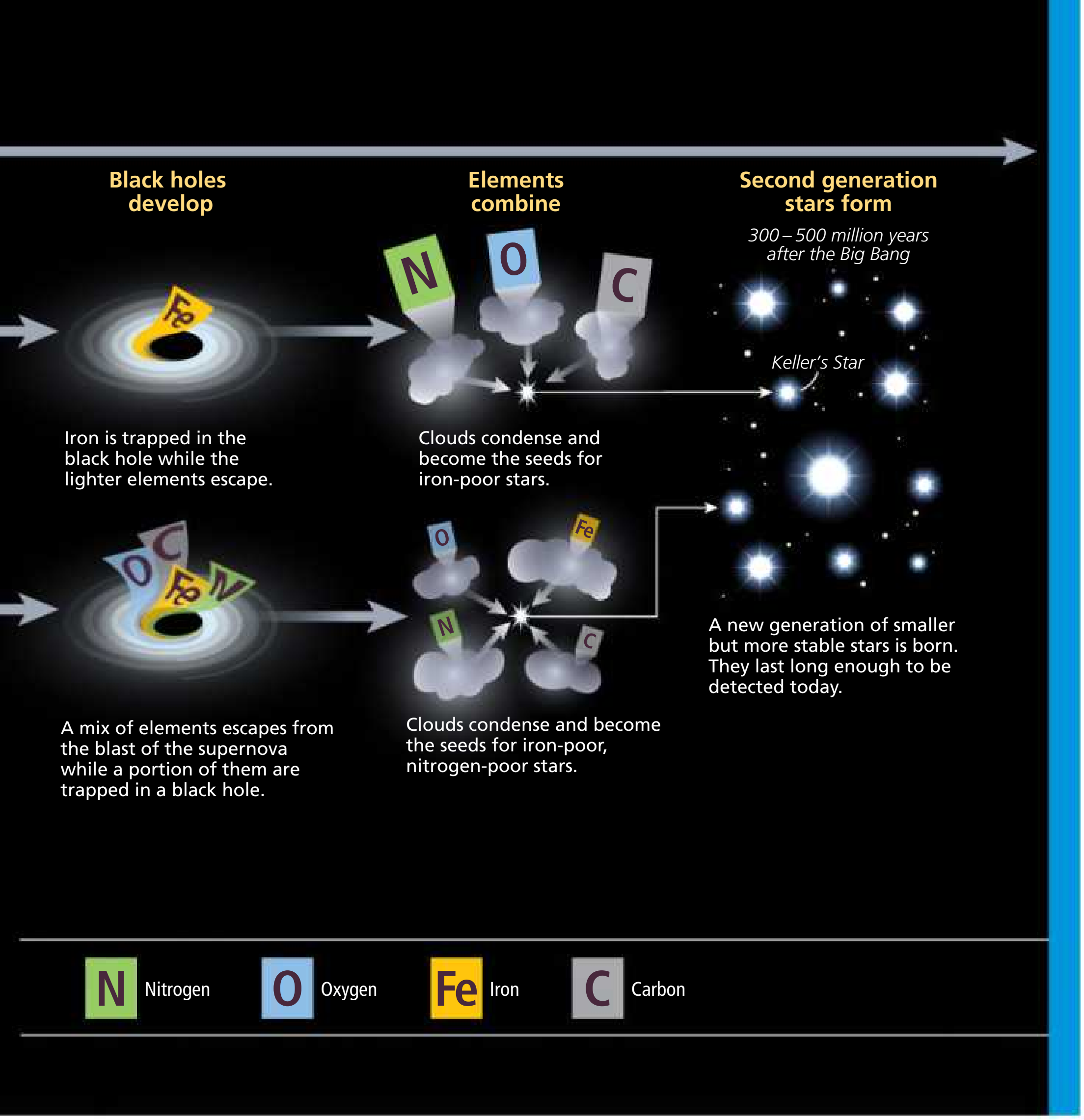
For some astronomers, the parallels are even closer. One of the great mysteries of the cosmos is how and when and why the first stars flared into light out of the darkness that followed the Big Bang. Nobody knows for sure what those first stars looked like, or how they lived and died. But their emergence set the stage for everything that followed — all of the planets, stars and galaxies that light up the night sky. Understand the first stars, and you understand how the universe took shape.

The gulf in time and space is so great that even the most powerful telescopes can't see the faint light from those first stars. But in recent years, a new breed of astronomers — stellar archaeologists — has realized there's a way to understand them by looking close to home, within and around the Milky Way. By examining the chemistry of the oldest nearby stars, they're beginning to understand the conditions in which those stars formed, conditions created in part by the short-lived and massive first generation of stars that came before. "We can still see their environmental impact, the pollution that these massive stars introduced," says Avi Loeb, head of the astronomy department at Harvard.

The good news is that second-generation stars are all around us. "Some of the best examples we have are just a few hundred light-years from us," says Timothy Beers, the provost's chair of astrophysics at Notre Dame. "They're really not that far away, and it tends to surprise people that we can understand the distant past by looking so close to home."

SEARCHING FOR THE SECOND GENERATION

Just because they're nearby, however, doesn't mean these second-generation stars are easy to find. In fact, "they're quite rare," says Loeb. In the Milky Way's spiral arms, most stars, including the sun, formed much later, when the universe was already middle-aged, about 4 billion to 6 billion years ago. And even in the core of the Milky Way, which formed earlier and where the odds are greatest of finding an ancient star, Loeb says, "they still represent less than 1 percent of all stars." Merely identifying which stars are truly old,



search for the oldest living stars is the search for those with only the faintest of impurities, usually expressed as the ratio of iron to hydrogen. The purer the star — the lower the iron-to-hydrogen ratio — the older it almost certainly is.

For decades, astronomers found such stars by chance, not realizing the archaeological promise they held. Right now, "we know of 50 or so stars that have less than one three-thousandth of the iron abundance in the sun. And there are six stars — only six — that have less than one ten-thousandth of the iron abundance," Loeb says. That would put their birth within an impressive half-billion years, at most, after the Big Bang.

Then, in February 2014, a team led by Stefan Keller of the Australian National University announced the discovery of a star with at most one ten-millionth as much iron as the sun. "It's a star with no iron in its spectrum whatsoever," says Michael Norman of the University of California, San Diego. "No one has ever seen a star like this."

That lack of iron suggests that Keller's Star, as it's known, could be the most ancient yet, possibly dating back to 200 million years after the Big Bang. Not only was it an amazing find on its own, but it also changed everything astronomers thought they knew about the first stars.

Despite its lack of iron, Keller's Star has measurable amounts of carbon, oxygen and other metals. "That's the really remarkable thing," says Beers. "We see a pattern that for the time being can only be explained by a population of first-generation stars."

therefore, is the first, tricky step.

One key factor distinguishes an ancient star from a youngster like our sun: its composition. The only elements that emerged from the Big Bang were hydrogen, helium and tiny bits of lithium, so that's what the first generation of stars must have been made of.

Heavier elements — including nitrogen, oxygen, iron, carbon and more — were forged in the nuclear furnaces at the cores of those first stars, then spewed into interstellar space when the stars exploded. "What's remarkable to me," says Beers, "is the elements that we associate with carbon-based life today are produced by the first-generation stars."

These liberated heavier elements, which astronomers call "metals" (even oxygen is a metal in astronomer-speak), contaminated the hydrogen and helium drifting between the stars. The second generation of stars would therefore include these ingredients — "environmental pollution" as Loeb calls it. These metals are the fossils stellar archaeologists search for, using a star's spectrum, or light signature, to probe its composition.

Second-generation stars are still metal-poor compared with modern stars like the sun, whose birth clouds were enriched by several generations of stars over billions of years. So the

UNDERSTANDING THE FIRST GENERATION

Originally, astronomers simply assumed that when the first stars went supernova, the explosions uniformly spewed their innards far and wide. But even before finding Keller's Star, they'd already begun to wonder if this picture was oversimplified.

"We've seen this distinctive element pattern in other old stars as well," Beers says — very little iron, but more of the other metals than you'd expect. The implication: Some first-generation or progenitor stars exploded evenly, as

expected, but others must have somehow held onto iron during their death throes while allowing lighter metals to spread out into space.

Key among these lighter elements is nitrogen. Some iron-poor stars (including Keller's) have a fair amount of nitrogen, while others have essentially none. "My suspicion," Beers says, "is that this variation in nitrogen tells us that we're seeing evidence for at least two classes of progenitor stars." Stellar archaeologists had found the stellar equivalent of Neanderthals, a separate but similar species that coexisted with our suspected forebears.

According to theorists like Volker Bromm of the University of Texas at Austin, the iron-poor, nitrogen-rich second-gen stars come from one specific class of progenitor stars with 10 to 100 times the mass of the sun. Simulations show that these stars would die in dramatic explosions that leave behind black holes, which would trap the heaviest elements in place. "Lighter stuff like carbon and oxygen and nitrogen will get out," says Bromm.

The other class of first-generation star, whose imprint is seen in iron-poor, nitrogen-*poor* stars, generally would have been even bigger, between 50 and 100 solar masses. (The apparent overlap between the two classes reflects uncertainties in the numbers, but modelers know for sure that this second category would have been more massive.)

"When stars this massive form," says Beers, "they tend to spin very rapidly." In contrast to the first group, the metals in these larger stars get churned up to the upper levels, so they're thoroughly mixed in when the star explodes. That means the black holes left behind swallow a representative mix of elements, not just the heavier ones — and that some iron is allowed to escape. Second-generation stars made from this debris would still have relatively little iron, like any other ancient star, but they'd have correspondingly little nitrogen as well.

So the first stars came in at least two distinct flavors, and astronomers suspected an even more rare third kind, downright enormous between 140 and 260 solar masses. These gigantic stars would have had surface temperatures of millions of degrees, making them not red-hot or blue-hot, but hot enough to produce gamma rays, the most energetic form of light. The laws of physics dictate that gamma radiation can decay into pairs of elementary particles: electrons and positrons. The star's gamma rays exerted outward pressure, keeping the massive star from collapsing, but once they'd turned into particles, that outward pressure would be gone, resulting in a catastrophic collapse. This would trigger gigantically powerful supernovas, known to astronomers as "pair-instability" supernovas, which would have added their own, slightly different mix of elements to interstellar gas clouds, and to stars that formed from them.

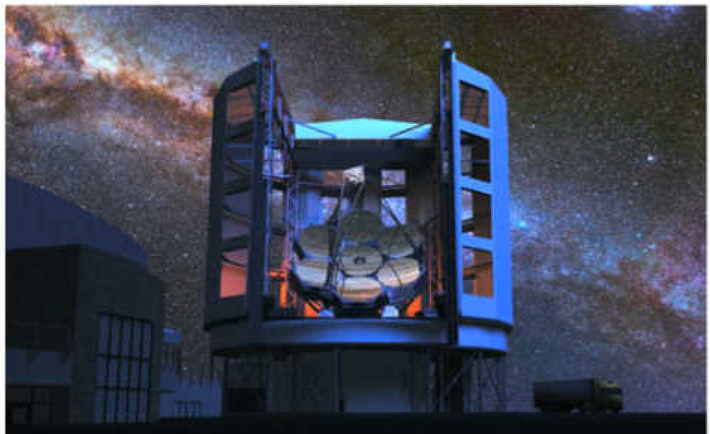
According to Harvard's Loeb, "one of the holy grails of searching for metal-poor stars is to find evidence for these early pair-instability supernovae." And sure enough, a Japanese team reported in *Science* in 2014 that a nearby star known as SDSS J0018-0939 is almost certainly a second-generation star bearing the chemical imprint of such an explosion.

FROM ANCIENT STARS TO ANCIENT GALAXIES

This three-species taxonomy of primordial stars might well reflect the mix of objects that first emerged after the Big Bang, but actual evidence has proven relatively sparse. That has begun to change, however, thanks to observers like MIT's Anna Frebel, who got her start in old-fashioned single-star stellar archaeology as an undergraduate in the early 2000s.

A few years ago, Frebel realized that some of the dwarf galaxies that orbit the Milky Way might be especially rich sources of ancient stars. In April 2014, she and two colleagues announced in the *Astrophysical Journal* they'd found the perfect candidate. A dwarf galaxy known as Segue 1 hovers just beyond the edge of our own. Simulations of the early universe suggest that galaxies like this were the first to arise, as hydrogen and helium gas began to clump together. They served as the building blocks for full-size galaxies by colliding into and merging with each other.

What sets Segue 1 apart from other dwarf galaxies is that it stopped forming stars when the second generation of stars



The Magellan Clay telescope (left) was key in finding Keller's Star; the upcoming Giant Magellan Telescope (above) will help study such stars.

TOP: GIANT MAGELLAN TELESCOPE–GMTO CORP. BOTTOM: ANNA FREBEL/MIT

appeared. Astronomers aren't sure why, but they posit that the tiny galaxy ran out of the gases that fuel star birth early on. Whatever the reason, the result is a gold mine for researchers like Frebel who seek more data on these ancient stars. "We think that most, if not all, of the stars in this galaxy were formed just a hundred million years after the Big Bang. And that," she says with more than a little understatement, "is kind of old."

That means Segue 1 could go a long way toward supplying theorists with the information they need to fully understand the first stars in all their variety — nothing less than a comprehensive picture of what the universe looked like when it lit up for the first time. The work is enormously painstaking, and so far, Frebel and her colleagues have only been able to determine that Segue's thousand or so stars are indeed very old.

Probing the finer details of those ancient, extragalactic stars'

chemical structures would take many years, even with the most powerful telescopes on Earth or in space. That's because Segue is far away (even if we're relative neighbors), and its stars are faint compared with the ones stellar archaeologists have studied to date. "At this point," says Bromm, "people like Anna have maybe a handful of high-quality spectra for the brightest stars." But things are likely to change before long.

A GARGANTUAN TASK

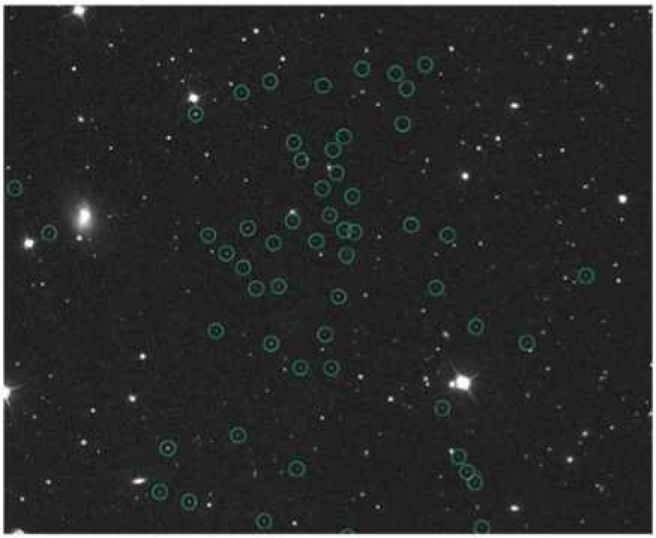
Stellar archaeologists are eager to get their hands on the new class of giant telescopes that will be going online in the early 2020s, including the Thirty Meter Telescope, the Giant Magellan Telescope and more. It used to be that astronomers had trouble finding enough stars to study. Now, with Segue 1 — and with Frebel on the lookout for other ancient galaxies — they have too many. The upcoming telescopes, with nearly 10 times the light-gathering power of existing instruments, should break the logjam.

"It's really an exciting time," says Bromm. "We now have these high-precision laboratories" — that is, second-generation stars — "which are telling us exactly what the universe was like at the very earliest times," he says. "Before this, we were only in the ballpark." And soon, astronomers will have the tools to study them in unprecedented detail.

Loeb agrees. Until now, astronomers have studied the early history of the universe directly, trying to peer farther and farther away at older light, in an attempt to tease out the secrets of how the cosmos first burst into light. "Now we're doing cosmology by digging right in our own backyard," he says.

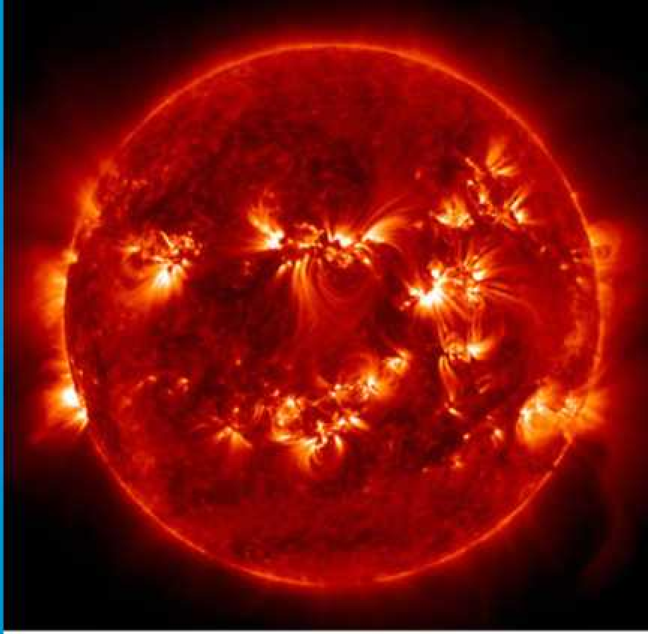
And it's paying off. "We have a reasonable grasp on the chapter titles in the story of the how the first stars appeared and what they looked like," says Beers. "Now we're starting to write the paragraphs." D

***Michael D. Lemonick** is a freelance writer and the author of six books, including, most recently,* Mirror Earth: The Search for Our Planet's Twin.



The stars of dwarf galaxy Segue 1 (circled in green) are a boon to stellar archaeologists because they're all extremely old second-generation stars.

TOP: SOLAR DYNAMICS OBSERVATORY/NASA. BOTTOM: MARLA GEHA/YALE UNIVERSITY



Solar Siblings

Most stellar archaeologists look for traces of the first stars in the universe, but Ivan Ramirez is interested in a more recent vintage. He wants to find the long-lost siblings of the sun — the hundreds or perhaps thousands of stars that condensed, along with our home star, from a single cloud of gas about 4.6 billion years ago.

"If we can figure out the detailed properties of the place where our sun and its planets formed," he says, "we might be able to find out if those conditions had anything to do with the fact that life exists here on Earth."

At first, he didn't like the odds. "It was a project that was most likely to fail," says Ramirez, an astronomer at the University of Texas at Austin. Although the sun's birth brood would have huddled together in a loose cluster at first, they would have gradually split up. By now, says Ramirez, "they could have wandered thousands of light-years away from us."

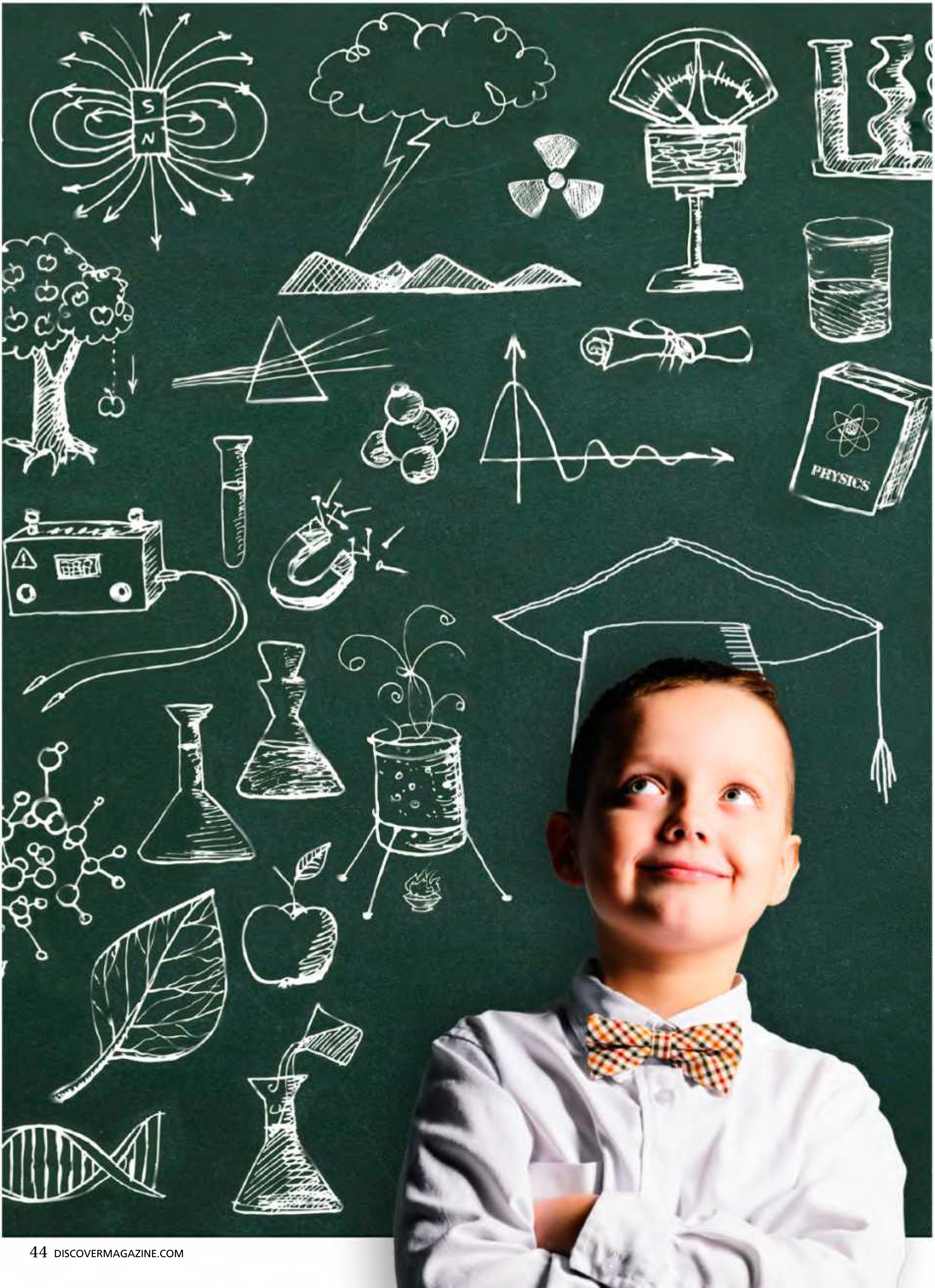
He and his colleagues didn't expect their modest 2012 search to find anything; they were just testing the techniques they'd eventually use for the real search. It was a welcome shock, then, when the team discovered a star called HD 162826.

Based on the star's location and motion, they calculated that it must have been very close to the sun billions of years ago. And when the astronomers analyzed its chemical composition, the match was uncanny. The practice run was already proven sound. "The actual discovery," Ramirez says, "was a bonus."

That future search is still in the works, and Ramirez hopes that improved technology, including the European Space Agency's Gaia satellite, will help him find even more solar siblings. "We should be able to find at least half of the stars that were born with the sun," he says.

And when they do, they'll know at last what the sun's long-lost birth family looked like — and the origins behind our star, Earth and everything that lives here. — ML

Read about the astronomers hunting for the universe's first stars at **DiscoverMagazine.com/FirstLight**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PHYSICS

GREAT Expectations

In the 1960s, a researcher lied to prove students would rise to meet their teachers' expectations. But no one could replicate those results without also lying — until now.

BY **KATHERINE ELLISON**

Beverly Cantello didn't appreciate being misled — at least, not at first.

It was 1964. Cantello was 23 years old and just starting out in her teaching career when a Harvard psychologist named Robert Rosenthal came to her elementary school. The principal announced that she'd given Rosenthal permission to administer a fancy-sounding new IQ test to the school's students that spring.

Shortly thereafter, Cantello was told that Rosenthal's Harvard Test of Inflected Acquisition revealed something remarkable: Small groups of children in each classroom were poised to "bloom" academically.

And indeed, over the next school year, the designated students at Spruce Elementary School in South San Francisco excelled, just as predicted. The youngest of them made the most dramatic gains: On average, these first-graders increased their IQ scores by more than 27 points.

Only then were Cantello and her colleagues informed that Rosenthal had not told the truth. The Test of Inflected Acquisition was just a standard IQ test. The "bloomers" had been chosen at random. It was the teachers' belief in their pupils' potential, not any innate advantage, that spurred the students to achieve.

"At first, I was offended. I thought, 'How dare they?'" recalls Cantello, now retired, on a recent afternoon in her sunny kitchen in San Rafael, Calif. "Later I understood why he needed to fool us."

Rosenthal struck gold with his now-famous findings. His study survived an extraordinary storm of controversy to become one of the most inspiring and widely cited breakthroughs in the history of psychology. "The bottom line is that if we expect certain behaviors from people, we treat them differently — and that treatment is likely to affect their behavior," says the psychologist, now 82 years old and still collaborating with researchers on nonverbal communication projects at the University of California, Riverside.

He called his discovery the Pygmalion Effect, after the mythological Greek sculptor whose love for the ivory statue of a woman he created inspired the gods to bring her to life. Similarly,

ILLUSTRATION BY DAN BISHOP/DISCOVER WITH IMAGES BY SERGEY PETERMAN/SHUTTERSTOCK, BESTPIX/SHUTTERSTOCK AND ELINA LI/SHUTTERSTOCK

In 1964, Robert Rosenthal (far right) gave an IQ test to students at the Spruce School (shown here in the 1960s; these children may or may not have been tested).

COURTESY OF THE SOUTH SAN FRANCISCO HISTORICAL SOCIETY

the researcher's deception gave a new lease on life to the lucky "bloomers." Many came from low-income Mexican families, and already by first grade they had been "tracked," according to teachers' expectations of their future performance. At a time when most scientists still believed IQ scores were genetically determined and fixed throughout life, the faux results of the Harvard Test of Inflected Acquisition bathed these students in a new, more optimistic light.

The discovery embodied the American dream — writ small enough to fit inside a classroom — and appeared to hold the promise to transform our educational system. Any student had the potential to "bloom," it would seem, under the right circumstances.

Half a century later, however, and to the frustration of many enthusiasts, this promise remains mostly a tantalizing possibility.

"The Pygmalion Effect is great science that is underapplied," complains retired Tel Aviv University Professor Dov Eden, who has been a career-long Pygmalion evangelist as a management consultant and psychologist for the Israel Defense Forces. "It hasn't made the difference it should have in the world, and that's very disappointing."

Eden's frustration, shared by many other researchers who have tried to replicate Rosenthal's stunning findings, stems from an important caveat to the apparent promise of Rosenthal's discovery at the Spruce School. In that experiment and hundreds of similar subsequent ones, the expectations Cantello and her fellow teachers had for their students were fruitful only when their behaviors were subconsciously driven, suggesting that they might not have been able to so earnestly alter their behavior if they had known the truth about their students from the beginning. This apparent need for initial deception would certainly seem to deflate any hope that the Pygmalion Effect one day could change the way we parent our children, run schools and factories and even train our soldiers.

But Rosenthal remains optimistic. There are some very good reasons, he contends, to maintain high expectations about high expectations.

They begin with his own childhood.

EARLY EXPECTATIONS

Well before his visit to the Spruce School, Rosenthal was the beneficiary of the kind of faith he'd later study. As the only son of German-Jewish Holocaust refugees, he was keenly aware of his parents' ambitions for him, no matter what pursuit he enjoyed. When he played sandlot football as a child growing up in Southern Rhodesia (now Zimbabwe) — the first step in his family's immigrant odyssey that later brought him to New York — his father encouraged him to pursue his interests, including becoming a professional football player (though he

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> The discovery embodied the American dream — writ small enough to fit in a classroom — and appeared to hold the promise to transform our educational system.

says he had nowhere near the aptitude to go pro). After his family subsequently settled in America, Rosenthal joined the U.S. Naval Reserves, prompting his father to speculate about his future career as an admiral.

Rosenthal instead pursued psychology, and true to his parents' expectations, he soon distinguished himself. While teaching at the University of North Dakota before being hired at Harvard, he devised a mischievous project that confirmed his early suspicions about the power of expectations. He asked a group of lab researchers to experiment with rats that he said were specially bred to be either exceptionally good or exceptionally bad at running through mazes.

In fact, there was no difference between the "maze-bright" and "maze-dull" rats, despite the labels that Rosenthal's student accomplices had attached to the cages. But, as Rosenthal predicted, the "maze-bright" rats ran the maze faster and more accurately than the dull rats. Perhaps the rats gained an edge because of the way the keepers anticipated the rats' behavior. Rosenthal, who was certain the experiment revealed a powerful and mostly subconscious dynamic, wrote about this discovery in a 1963 article in *American Scientist*. In the article, he speculated that "if rats became brighter when expected to, then it should not be farfetched to think that children could become brighter when expected to by their teachers."

This prompted a letter from Lenore Jacobson, the Spruce School principal. "If you ever 'graduate' to classroom children, please let me know whether I can be of assistance," she wrote. Rosenthal didn't keep her waiting.

SPLASH AND BACKLASH

Rosenthal and Jacobson would later collaborate on a book on their famous study — disguising the school's location by referring to it as "the Oak School." In the weeks leading up to the 1968 publication of the book, *Pygmalion in the Classroom*, Rosenthal was ballyhooed in a front-page story in *The New York Times*, and in an interview with Barbara Walters on the *Today* show.

Then came the attacks.

"Pygmalion is so defective technically that one can only regret that it ever got beyond the eyes of the original investigators!" wrote Columbia University's Robert Thorndike, an expert in educational and psychological testing and one of several prestigious scholars who lambasted Rosenthal's project. Thorndike, who died in 1990, charged that Rosenthal used faulty data from the first IQ test, including what Thorndike said were impossibly low initial IQ levels, which, he suggested, skewed the later results. At the time, Rosenthal countered that even if the initial test results were faulty, that didn't invalidate the subsequent increase, as measured by the same test. Moreover, Rosenthal says, the design for the experiment Thorndike found so flawed had previously won an award from the American Psychological Association.

Some of the critics were plainly politically motivated. Albert Shanker, founder and future president of the United Federation of Teachers, rebuked the Pygmalion experiment in his regular Sunday column in *The New York Times*, suggesting that it vilified teachers:

> *"If thousands upon thousands of children are not learning to read, write, speak and compute, it is not because of overcrowded classrooms, the effects of poverty and social conditions, poorly developed educational programs and materials and inadequately trained teachers. No, the children are not learning because the teachers don't expect them to learn."*

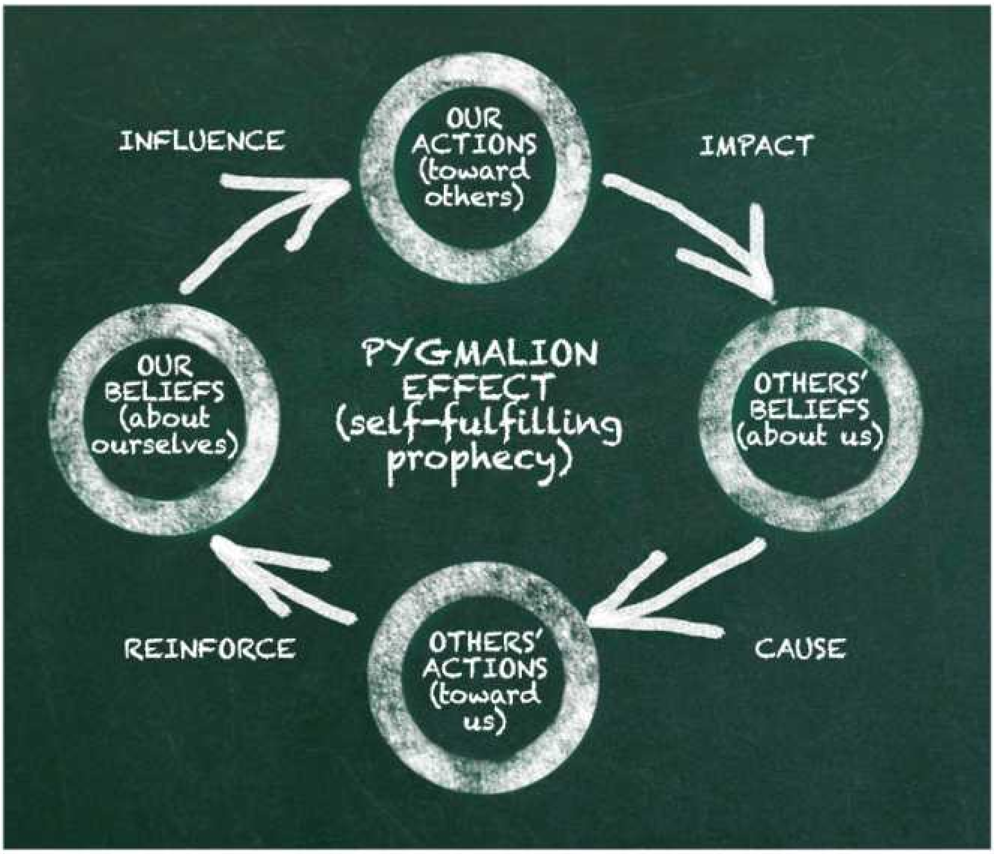
Rosenthal says he was stung by the ferocity of the criticism, especially when it came from such prestigious critics. Yet, he adds in his usual mild-mannered tone, "I don't think any of them were scientifically sound."

Even so, as he continued to share his data with all his major challengers and patiently respond to their critiques, Rosenthal keenly decided to team up with a doctoral student named Don Rubin, who would go on to serve for more than 13 years

as chief of Harvard's Department of Statistics. "Eventually, it became a case of 'My statistician is smarter than your statistician,'" Rosenthal jokes.

In 1978, 10 years after the study's debut, Rosenthal and Rubin co-authored a report summarizing 345 experiments involving the influence of interpersonal expectations. "The reality of the phenomenon is beyond doubt," they concluded. The critics eventually quieted down, and the Pygmalion Effect became dogma.

The Spruce School experiment, now a classic lesson in psychology and education classes, has since inspired legions of teachers. It also helped fuel a backlash in the 1970s and 1980s against "tracks" and "ability groups" for students. In October 2014, researchers for the liberal advocacy group Center for American Progress cited the Pygmalion Effect as an argument in favor of the new, more rigorous Common Core State Standards, a bold education reform adopted by more than 40 states starting in 2010. They said national education data showed that, all else being equal, "10th-grade students who had teachers with higher expectations were more than three times more likely to graduate from college than students whose teachers had lower expectations."



DAN BISHOP/DISCOVER

REAL-WORLD RESULTS

Meanwhile, over the past five decades, scores of scientists inspired by Rosenthal have tracked Pygmalion effects outside of educational settings. They've documented evidence of it in family homes, courtrooms, military training centers and businesses — anywhere where inspired leadership can make a difference.

According to these reports, when managers have high hopes for their employees, the workers become more productive. When military instructors believe trainees have superior skills, the trainees perform better. Furthermore, when college men converse by telephone with women they've been told are attractive, they believe the women behave in more attractive ways.

Just last year, OKCupid co-founder Christian Rudder wrote a blog entry brazenly titled "We Experiment On Human Beings!" describing what appeared to be a new, digital Pygmalion Effect. Rudder disclosed that site managers testing the online dating site's algorithm had told poorly matched couples that they were, in fact, good matches. As a result, Rudder wrote, the couples behaved accordingly and engaged in more extended email conversations.

Low expectations may be just as influential. Scientists have chronicled the impact of negative expectations in settings where they occur naturally, such as classrooms that "track" students from early youth and in society's treatment of stigmatized groups such as racial minorities, the poor, the elderly, the homeless, convicts and children with learning disabilities.

In a study published last year in the *Journal of the American Medical Association*, researchers described a poignant example of this dynamic after they followed nearly 5,000 low-income families who moved out of public housing and into better neighborhoods. They found that while the daughters in those families benefited from the move, the sons still tended to fail both socially and psychologically, concluding there were "increased rates of depression, PTSD and conduct disorder among boys and reduced rates of depression and conduct disorder among girls."

The study's lead author, Harvard Medical School Professor Ronald Kessler, suggested in a published interview that, among other possible factors, biases about low-income boys might be to blame. "Boys may appear to be 'tough guys' and people then say they are 'problem kids,'" he said. "So the communities are responding to the boys in a different way than they do to girls."

Social reformers cite the Pygmalion Effect as key to reversing this sort of prejudice and encouraging child achievement. Yet there's one major problem with such high hopes. To date, neither Rosenthal nor his many followers have been able to

match the striking results from the Spruce School, or with his "maze-bright" and "maze-dull" rats, without first telling lies. This leads to a vexing question: Could the Pygmalion Effect be truly powerful only when expectations are subconscious?

Rosenthal and other researchers have spent decades trying to solve this puzzle, in hopes of finally bottling the Pygmalion magic to provide real-world benefits. Toward this end, in the 1980s, Rosenthal started studying covert communication: the nonverbal language of vocal tone, facial expressions, posture and gestures that make up the bulk of human expression.

Eventually he proposed four key factors that could help explain how teachers' expectations influence students. They boil down to climate (warm and friendly behavior), input (the tendency for teachers to devote more energy to their special students), output (the way teachers call on those students more often for answers) and feedback (giving generally more helpful responses to the students for whom teachers have the highest hopes).

MAKING BELIEF

So how might teachers or other leaders communicate these high expectations? What are their facial expressions, vocal tones and gestures like in these interactions? Alas, Rosenthal's research hasn't answered these questions, and there isn't much guidance from other nonverbal communication authorities. Paul Ekman, a leading expert in the field who has never collaborated with Rosenthal, says that as a general rule, people communicate these high hopes via the degree to which they physically show their attentiveness. A fixed gaze and raised eyebrows conveys a different message than a wandering gaze and bored expression. In other words, it's all a matter of emotional investment and focus.

This leads to a vexing question: Could the Pygmalion Effect be truly powerful only when expectations are subconscious?

These behaviors are usually instinctive, however. So the question remains: Can they be effectively taught? In the twilight of his career, Rosenthal sees signs that they can. He's particularly excited by the work of educational researcher Christine Rubie-Davies and her Teacher Expectation Project in Auckland, New Zealand. Between 2011 and 2013, Rubie-Davies ran workshops for nearly 200 teachers. She provided classroom instruction in the power of high expectations and the methods of high-expectations teachers, while also videotaping instructors while they interacted with students to show them their demeanor while they taught.

She says the videos have offered potent reality checks, adding: "I've watched teacher after teacher saying things like, 'Oh my God, just look at me! I had no idea I was raising my eyebrow or shaking my head like that!'"

Early this year, Rubie-Davies published a study based on an experiment in which she randomly assigned 84 teachers to either the workshops or regular professional development. She found that students taught by the high-expectations group made significant gains in math compared with the control group. On average, they ended the instruction year three months ahead of their peers.

Rubie-Davies isn't the first researcher seeking ways to train teachers to be better Pygmalions. Since the early 1990s, Robert Pianta, dean of the Curry School of Education at the University of Virginia, and his team have studied several thousand teachers, looking closely at their moment-to-moment interactions with students. In a 2011 controlled study published in *Science*, Pianta reported that his own training program had also boosted student performance, achieving the equivalent of moving the average student from the 50th to the 59th percentile in standardized test scores.

Like Rubie-Davies, Pianta videotapes his teachers to help make them aware of the little winces, shrugs and frowns through which they subconsciously speak volumes. More generally, Pianta has been encouraging the instructors to communicate higher expectations by turning over some of the control in the classroom to the kids: letting them work in teams on independent projects, for instance, instead of simply lecturing. That's a risky proposition for many educators, but with a little real-time encouragement and trial and error, teachers usually see that their students are capable of more than they may have imagined.

"I don't think you have to lie to teachers to get them to that point," Pianta says. "They just need a deeper understanding of children's cognitive and emotional development, and how fluid that is, and how closely it may be tied to their relationship with their teacher."

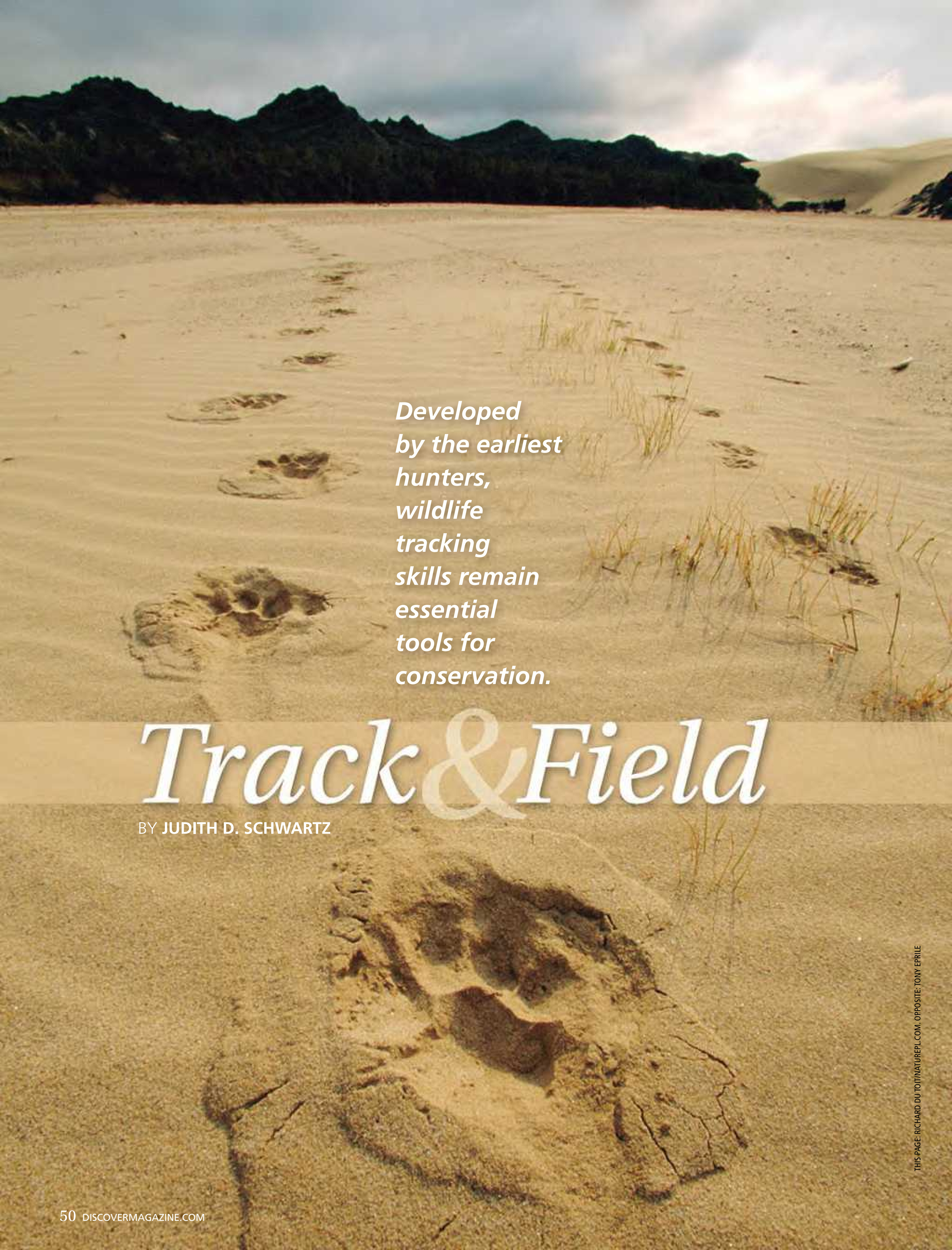
That's hopeful news, particularly given that it's now impossible for anyone to replicate Rosenthal's Pygmalion experiment. Not only are ethical standards for research much stricter, but most U.S. teachers are at least vaguely familiar with the findings at Spruce Elementary School and wouldn't be so easily duped.

Nonetheless, Beverly Cantello remains grateful for having been part of Rosenthal's historic experiment, even if she did so unwittingly. At the dawn of what would be her 36-year teaching career, the experience made her powerfully aware of the value of high expectations and positive reinforcement, regardless of students' prior performance. In subsequent years, Cantello developed sophisticated lesson plans for her second-graders. She challenged them by introducing them to the artwork of Salvador Dali, Claude Monet and Georgia O'Keeffe, and teaching them geography by having them produce a daily around-the-world weather report.

Like so many other good teachers, Cantello says she has since kept in touch with former students, continuing to encourage them as they've moved on to college and careers.

In her eyes, she says, every child she has taught has been a potential bloomer. D

Katherine Ellison *is a Pulitzer Prize-winning former foreign correspondent and author of several books, including* ADHD: What Everyone Needs to Know, *published in November.*



Developed by the earliest hunters, wildlife tracking skills remain essential tools for conservation.

Track & Field

BY **JUDITH D. SCHWARTZ**

THIS PAGE: RICHARD DU TOIT/NATUREPL.COM. OPPOSITE: TONY EPRILE

A barefoot Allan Savory at rest during a walk at Dimbangombe, his ranch in Zimbabwe, also the home of the Africa Centre for Holistic Management. Here, Savory merges tracking skills with principles of land use.

Allan Savory crawled through the dense brush, feeling for indentations beneath the leaves, signs of a lion. Two hired trackers from Botswana had long abandoned the quest, so it was up to him to capture the predator that was killing local cattle.

For several hours, Savory tracked both the lion and the trackers. Past the point where trackers lost the path and veered away, he kept on, following "grains of sand on top of fallen leaves," he says. But eventually, the sand dwindled to nothing. In the teak forest, nightfall was approaching. He was losing the light.

As a ranger with the Colonial Service in Northern Rhodesia (now Zambia) in the 1950s, Savory frequently found himself on the trail of rogue elephants and man-eating lions. For particularly high-risk fauna, the rangers usually relied on native trackers. Savory noticed, however, that when it came to lions, particularly those that developed a taste for humans, the trackers invariably "lost" the trail to avoid an encounter. If he was to do his job, he had to teach himself to track.

Thus it was that he now found himself at dusk on his hands and knees, maneuvering through the undergrowth, drawing on what he'd learned from observing native trackers and the nuances of the landscape to help him catch a wild animal that could very well kill him. He continued creeping along the forest floor for some 30 or 40 yards until he came to a narrow part of the bush that the lion had gone through.

"So I crawled through very quietly, but being so narrow, I had to push my rifle ahead of me," Savory recalls. He didn't want to go any deeper into the bush with the rifle's safety catch on. He released it as gently as he could, but the click was still audible. "The lion heard that, so it growled and rushed off," he says. It was only 10 yards ahead.

As a ranger in the 1950s, a younger Savory often found himself on the track of man-eaters long after local trackers conveniently "lost" the trail. His skills would serve him in a tracker combat unit a decade later.

In an era of satellite-driven data, with detailed info about virtually any dot on a map, tracking has lost much of its life-and-death urgency for the rest of us.

STEPCHILD TO SCIENCE?

These days, Savory is best known for developing Holistic Management, a decision-making process for land use in which practitioners manage livestock so that their behavior mimics that of their untamed counterparts. Experiences like that close call with the lion play into his work today: Savory believes his tracking skill enabled him to develop the Holistic Management framework. Only a tracker would drop to all fours to assess marks and patterns on the soil surface and envision the precise action of hooves that created them.

Tracking is an art that has guided Savory through several decades of stalking wild game and, later, guerrilla warfare. It also has contributed to key insights about how animal behavior can be harnessed to improve the condition of the land, especially in regions like his native Zimbabwe with long dry seasons during which ruminants are conveyers of soil fertility and moisture.

But in an era of satellite-driven data, with detailed information about virtually any dot on a map, tracking has lost much of its life-and-death urgency for the rest of us. This raises the question: Is tracking still relevant, or is it merely a quaint, lesser stepchild of modern science?

"I don't know a better way to teach observation, deduction and reasoning," Savory says. Indeed, recent years have brought new applications of tracking for ecological research and conservation. So rather than being a dying art, tracking may be coming into its own.

Tracking is as old as mankind. The earliest hominins hunted and therefore engaged in simple, or systematic, tracking, says Louis Liebenberg, the South African author of *The Art of Tracking: The Origin of Science*. Systematic tracking entails following an animal, using clues and signs like spoor (tracks, scent or droppings), displaced stones or trampled grass for guidance. You're sticking to empirical evidence, no guesswork.

In speculative tracking, the tracker anticipates an animal's actions. You're projecting yourself into the animal's mind based on knowledge of animal behavior and the terrain, says Liebenberg. Speculative tracking trades in prediction and possibility and allows the hunter to stalk prey and be alert for shortcuts. Evidence of the bow and arrow dates to about 70,000 years ago, he says, suggesting that speculative tracking was used by that time.

"Speculative tracking reflects the essence of science," he says. The tracker assesses signs in the environment to construct a working hypothesis about the animal and its whereabouts, which would be confirmed or disproved as the evidence emerges. "It's about the human imagination," he says. "A physicist can only see signs of a particle but cannot see the particle itself."

Liebenberg's interest in tracking, like Savory's, arose from experience in the African bush: Out of interest and curiosity, he began observing and drawing animal tracks while serving in the military in northern Namibia. Liebenberg had important mentors, including master trackers of the Bushmen, or San people, in the Kalahari Desert in Botswana.

Liebenberg regards tracking not just as the foundation of scientific endeavor — he suggests it drove the development

COURTESY OF ALLAN SAVORY

Savory at Dimbangombe, where the tracks of sable, baboons, elephants and other wildlife are abundant and obvious — if you know what you're looking for. "I don't know a better way to teach observation, deduction and reasoning," he says of tracking.

SARAH GLEASON/SAVORY INSTITUTE

of human intelligence. He believes this is supported by the increased intellectual sophistication required as tracking evolved. Liebenberg's theory is that scientific thought arose from tracking. The analytical skill required "says something about what makes humans unique: the ability to make causal connections," he says.

He regards the development of speculative tracking as particularly relevant to the scientific enterprise. This is where cognition took a leap. The tracker is not just observing signs but using the signs to pose "what if" questions like, "If the animal is looking for cover, where might it go?"

While we'll never know the exact trajectory of our intelligence, skills like tracking "are part of the development of the human genus as well as the human genius," agrees Daniel Lieberman, a professor in Harvard's Department of Human Evolutionary Biology, where Liebenberg is an associate. Scientific logic and understanding was needed among all hunter-gatherers, he says. "You have to be a naturalist, and to formulate and test hypotheses."

LOOKING 20 YARDS AHEAD

At the Africa Centre for Holistic Management in Zimbabwe, about 12 miles south of Victoria Falls, Savory takes his wooden walking stick and traces marks on the ground. "That's a sable hoof. Baboons have been here. Elephants were here recently," he says. He draws my attention to lines and indentations of varying degrees of legibility: signs of the wealth of animal life on the Centre's land.

To me, it was a spot like any other we'd walked or driven through that morning: mats of yellow grasses over rich, red earth and scrubby trees with only the occasional winterthorn showing green. But Savory found plenty of animal signs.

At nearly 80, Savory is slight and nimble and keen to his surroundings. He wears green khaki shorts, a light cotton shirt and a wide-brimmed felt hat — but no shoes. He says this benefits tracking. "With every single footstep, I'm conscious of the temperature of the soil and its texture. Here, it's cool," he says, pressing a foot into the ground. Later, when the ground is too hot, he'll reluctantly don a pair of Crocs or his thin-soled kudu-skin shoes that flap open where they're worn through.

For Savory, tracking brought together his two passions: wildlife and the military. He grew up during World War II and was steeped in the romance of battle. "I was fiercely proud of Rhodesia's role in the war," he says. He considered attending the British Royal Military Academy in Sandhurst. "I didn't want to be a peacetime soldier, so I went with my other passion, the bush."

In the 1960s, at the start of the long civil war that yielded Zimbabwe's independence, Savory was able to use his tracking expertise. He developed tactics suited to bush guerrilla warfare and established the Tracker Combat Unit that became the elite Selous Scout regiment, renowned for its counterinsurgency successes.

"I worked them from dawn to dusk," Savory says. "You get splitting headaches because you have to concentrate without stop. There are no coffee breaks. If you're at risk of getting shot at, you can't afford to miss any cues."

Since then, he has consulted on military tracking and countertracking — how to avoid being tracked. Over many years as a ranger, soldier and farmer, he studied the landscape and sought to understand why protected areas in southern Africa continued to deteriorate. While visiting a ranch in South Africa, it came together for him: He noticed a corner of a paddock where a large number of sheep had grazed for a short while. The animal impact had improved the soil so that seedlings were sprouting and the water had soaked in rather than run off.

He crouched to get a closer look. Where the sheep had been, the rich, moist soil was nourishing plant life. Elsewhere, the ground was hard and dry, and there were bare patches between plants. This led him to appreciate that animal disturbance could benefit as well as harm a landscape, and that this was how wild herds of grazing animals had maintained native grasslands.

The insight that sparked Holistic Management was that livestock could be made to act upon the land as their untamed counterparts had done. In practice, the holistic rancher constantly evaluates land condition and adjusts management accordingly. Doing this well depends on sharp and timely observation — just what tracking teaches.

For Savory, the African bush is alive and full of stories. He gleans the who, what, when and why of the land.

"When I walk around, this is what I'm looking for, to see what's been visiting. Here's a giraffe, a cow." He explains that a bull giraffe's footprint would be slightly larger. When I focus in, I can see that the giraffe's hoof marks are more elongated. I picture the animal that created it: a lanky browser with an improbably long neck, shoulder muscles rippling as it runs.

While trackers have deep knowledge of animals and ecology, many are excluded from science because they cannot read or write.

"When you're tracking, you're always looking 20 yards ahead," he says. "Then you look down to interpret a series of signals. You're thinking, 'Was there a wind in the night? What was the angle of the sun?' You've got to be aware of every single thing. The weather today. The weather yesterday. You're always asking, 'Why was tracking easier — or harder — yesterday?' What does that tell us about the condition of the land, and whether animals might be seeking water or shelter?"

A tracker is always observing, he says, "a lot more than people are used to, and coordinating it all instantaneously.

Not consciously, more like a tennis player, who's not thinking of how to hit the ball." He kneels down. "This could be old hyena spoor, or baboon. It's too windblown to tell." We're more than a mile from the main road, and it's still and quiet, except for the soft chirping of birds. "Most people would drive by and say, 'Oh, nothing is here.'"

TRACK TO THE FUTURE

Tracking may not be dying, but rather being adapted for the 21st century. Liebenberg, for one, wants to make sure this is the case. He's long noted the irony that while trackers have deep knowledge of animals and ecology, many are excluded from science because they cannot read or write. To that end, in 1997 he teamed up with a software developer to create CyberTracker, a GPS-supported application for tracking data collection using smartphones or older handheld devices. The interface features icons so that illiterate trackers can share and receive field observations.

The notion of tracking with a computer may seem at odds with the primal image of stalking prey in the bush. Yet Liebenberg says trackers have never shunned new instruments. "Traditional tracking was driven by technologies, like the bow and arrow," he says. "That technology, however, is disappearing. Therefore, the CyberTracker would replace the bow and arrow as a driver of the actual tracking."

One goal of CyberTracker is to bring dignity back to the

ALL IMAGES: ROLEX/ERIC VANDEVILLE

Left: Louis Liebenberg, co-creator of the CyberTracker software for collecting tracking data. Below: Compatible with current smartphones and tablets as well as older handheld devices, the GPS-supported application allows native trackers to share and receive field observations. Right: CyberTracker uses a pictographic interface so that neither language nor literacy will pose a barrier to sharing information. Modern tools like this can aid in everything from animal population surveys to anti-poaching efforts.

craft by highlighting the value of tracking skills. And by making the program accessible to non-readers, CyberTracker offers a vehicle for employment to native trackers so they can maintain those skills. Like Savory, Liebenberg contends tracking can contribute to many fields, from research and conservation to crime prevention. Tracking techniques are useful when monitoring nocturnal or reclusive species. For example, CyberTracker has been used in surveys of river otters, which are difficult to count.

"Tracking is inherently part of animal conservation," says Jean-Gael Collomb, executive director of the Wildlife Conservation Network, a U.S.-based support and programming nongovernmental organization for conservation efforts in the field. Even with modern technologies, tracking skills play an important role, he says. When using radio collars on lions or wild "painted" dogs, for example, you still need to locate and secure the animal. At the same time, he says, technologies like radio collars can enhance effectiveness of traditional tracking.

Kenya-based elephant ethologist and conservationist Joyce Poole agrees that tracking and technology can build on each other in a way that invites participation in conversation science. Her organization, ElephantVoices, has developed Mara EleApp, a smartphone app for monitoring elephant signs, sightings and mortalities. Categorizing the age of footprints, dung and rub marks on trees was made far easier by "sitting down with the Maasai and learning," she says. The app invites citizen science to contribute to a database. "We can learn which routes are important to elephants, which areas should be protected to sustain their movement, and where elephants are being killed," she says.

Tracking skills and tools are in demand to stop elephant and rhino poaching, which, regrettably, have reached crisis proportions. Both CyberTracker and Mara EleApp track animal movements to note vulnerable positions. Anti-poaching patrols use these tools to monitor poachers, such as holes in the fence or other places they might enter the park so as to pre-empt or even catch them, says Liebenberg.

The best poachers are, by definition, good trackers, he says, which makes outmaneuvering them a challenge. Liebenberg has helped to organize intensive tracking training for park rangers and is seeking money to upgrade the CyberTracker software to allow for two-way exchanges in real time. One reason, he says, is "so poaching syndicates cannot hack in. They have money to pay hackers to do so. The only way to get around this is to give people [in areas where there are rhinos] better jobs."

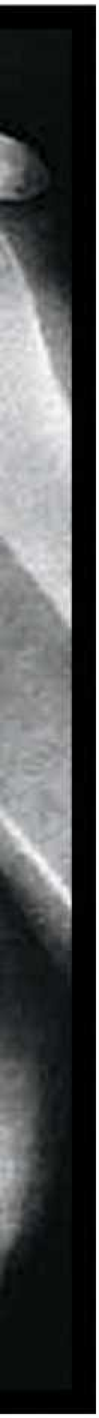
In other words, rather than waning, the art of tracking may be on the verge of a renaissance — with high-tech apparatus replacing the trusted bow and arrow or spear. D

Judith D. Schwartz *is a journalist and author of the forthcoming* Water in Plain Sight: Hope for a Thirsty World *(St. Martin's Press). This story was produced in collaboration with the Food and Environment Reporting Network, a nonprofit news organization focusing on food, agriculture and environmental health.*

CRAZY HEART

One German doctor's daring deception helped build the basis of life-saving cardiac imaging.

BY **JAMES S. FORRESTER**



Going under the knife for heart surgery would make anyone anxious, but thanks to advancements in medicine, most of us can rest easy knowing that risks for complications are pretty low. In the early days of cardiac surgery, though, it wasn't uncommon for someone to die on the operating table due to preoperative misdiagnosis.

Because early surgeons and cardiologists had to base their preoperative cardiac diagnoses on their stethoscope, the heart's X-ray silhouette and the ECG, their diagnoses were imprecise. Surgeons, thinking they were operating on a simple hole in the heart, opened it to find additional complex abnormalities of valves for which they had no surgical solution. Desperate children died on the operating table or soon thereafter as surgeons tried to explain the mistaken diagnosis to grieving parents.

Cardiac surgeons needed preoperative images of the chambers, valves and the inflow and outflow blood vessels. And so it was that another tragedy of cardiac surgery stimulated the development of X-ray suites, called catheterization laboratories, devoted solely to analysis of the heart.

The origin of cardiac catheterization is the most improbable story in all of cardiology, indeed in all of medicine. It begins just before World War II in a small German hospital, less than an hour's drive northeast of Berlin in the forest town of Eberswalde (literally, "Forest of the Boars").

In 1929, unknown 24-year-old resident-in-training Werner Forssmann became obsessed with an idea. He reasoned that the concentration of drugs acting on the heart would be much higher if they were delivered directly into the heart's chambers rather than being diluted by injection into a peripheral vein. He could push a tube from an arm vein all the way through into the right atrium. No one had ever tried this, or if they had, never admitted it.

Conventional wisdom held that, like surgery on the heart, pushing a tube into the heart carried a great risk of inducing ventricular fibrillation — when the heart's muscles don't contract normally and pump little to no blood — and certain death. Forssmann's support for his idea was gossamer-thin: He read that 75 years earlier, some Frenchman conducted this very experiment on a horse. Nonetheless, he proposed his idea to Peter Schneider, the hospital's chief physician.

Schneider's answer was swift, appropriate and unequivocal.

"I cannot possibly allow you to carry out such an experiment on a patient."

Forssmann's response suggested a touch of insanity. He countered that his commitment to his idea was so profound that he would accept the risk by passing a catheter on himself. Schneider, shocked by the young doctor's absurd and grandiose response, countered with the finality of the kaiser.

"My no is final and absolute." Forssmann was absolutely prohibited from pursuing his crazy idea further.

Forssmann pretended to be humble and to accept his rejection. After all, he was completely boxed in because he had no catheter. He did not even have access to the necessary surgical supplies, which

In 1929, Werner Forssmann (top) defied orders and pushed a catheter up his arm and into his heart (opposite). His stunt, based only on accounts that veterinarian Auguste Chauveau (above, right) successfully catheterized a horse's heart 75 years prior, was the first human heart catheterization.

the hospital kept under lock and key. But he had one asset that Schneider had failed to consider. Forssmann was an eligible young doctor in a sea of nubile nurses and so hatched a scheme of headstrong defiance.

"I let a few days go by and then started to prowl around Nurse Gerda Ditzen like a sweet-tooth cat around the cream jug. … It was easy to find something to gossip about, and she'd invite me back to her little office. … So little by little I won over my essential disciple," he recounted in his memoirs. She was indeed essential. Ditzen was the keeper of the keys to the hospital's closet of sterile supplies.

After two weeks of Forssmann's amorous charm, Ditzen was so thoroughly smitten that she seemed bereft of all judgment. What followed is almost beyond imagination. She walked to a cabinet, unlocked it and extracted a scalpel, a vial of local anesthetic and a catheter designed to empty urine from the bladder. Ditzen and Forssmann then strolled to an isolated empty hospital room and closed the door behind them. Ditzen lay down supine and helpless before Forssmann. He had convinced her to be the first subject in his mad scheme. With Ditzen willingly defenseless, Forssmann moved with the alacrity of an obsessed scientist.

"With the speed of light, I strapped her down so tightly that she couldn't reach the buckle. Then I tied down her hands. Amazingly enough, she accepted my explanation that I had to take all these precautions against her falling off the table, since I had no one to assist me. I had pushed the instrument table behind her head so she couldn't see what I was doing," he said.

Did Forssmann possess the charm of Rasputin, able to separate an apparently well-adjusted nurse from her most basic impulse of self-preservation? Having mesmerized his prey, was he actually going to proceed with an unthinkable assault on a healthy young woman? Every doctor, regardless of his native language, knows *primum non nocere*, Latin for "first do no harm" and the keystone of medicine's ethical code. Was Forssmann really prepared to sacrifice his career and, even worse, endanger the life of an infatuated woman, possibly kill her, just for his idea?

"In the twinkling of an eye I had anesthetized my left elbow. … I quickly made an incision in my own skin … and pushed the catheter about a foot inside. I packed it with gauze and lay a sterile splint over it. Then I released Gerda's right hand and loosened the straps around her knees."

With the urinary catheter protruding from his arm like an emerging snake in a horror movie, he and a pale and speechless Ditzen hustled past disbelieving nurses all the way to a fluoroscopic X-ray suite in the hospital basement. The X-ray technician, wanting no part of what was happening, bolted from the room. Moments later, Forssmann's drinking buddy Peter Romeis, awakened from an afternoon nap by the terrified X-ray technician, barreled into the room screaming at Forssmann to terminate his rendezvous with death.

Forssmann, always stubborn and reckless but now deeply invested in his plot and righteous in his crusade, was adamant. He turned on the fluorescent screen used to capture and view X-ray images.

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"As I'd expected, the catheter had reached the head of the humerus (the tip of the shoulder). Romeis wanted me to stop at this point and remove it. But I wouldn't hear of it. I pushed the catheter in further, almost to the 2-foot mark. … Romeis tried to pull the catheter from my arm. I fought him off, yelling, 'Nein, nein, I must push it forward.' I kicked his shins and pushed the catheter until … the tip had reached my heart."

And nothing happened. No sudden arrhythmia, no ventricular fibrillation, no collapse to the floor.

Forssmann ordered, "Take a picture." The X-ray image (pictured at the beginning of this story) showed the catheter in the right atrium. The tube was too short to be advanced farther.

Now Forssmann had to face Dr. Schneider, who flew into Teutonic rage when he learned of Forssmann's rank disobedience. Yet his fury abated as he stared in astonishment at the young doctor's X-ray images. Forssmann had put a catheter in the heart and suffered no problem whatsoever. Schneider was of two minds. Did Forssmann's act of disobedience represent a medical curiosity or an important advance? Could a tube within the heart itself be of value in treating a deathly ill patient?

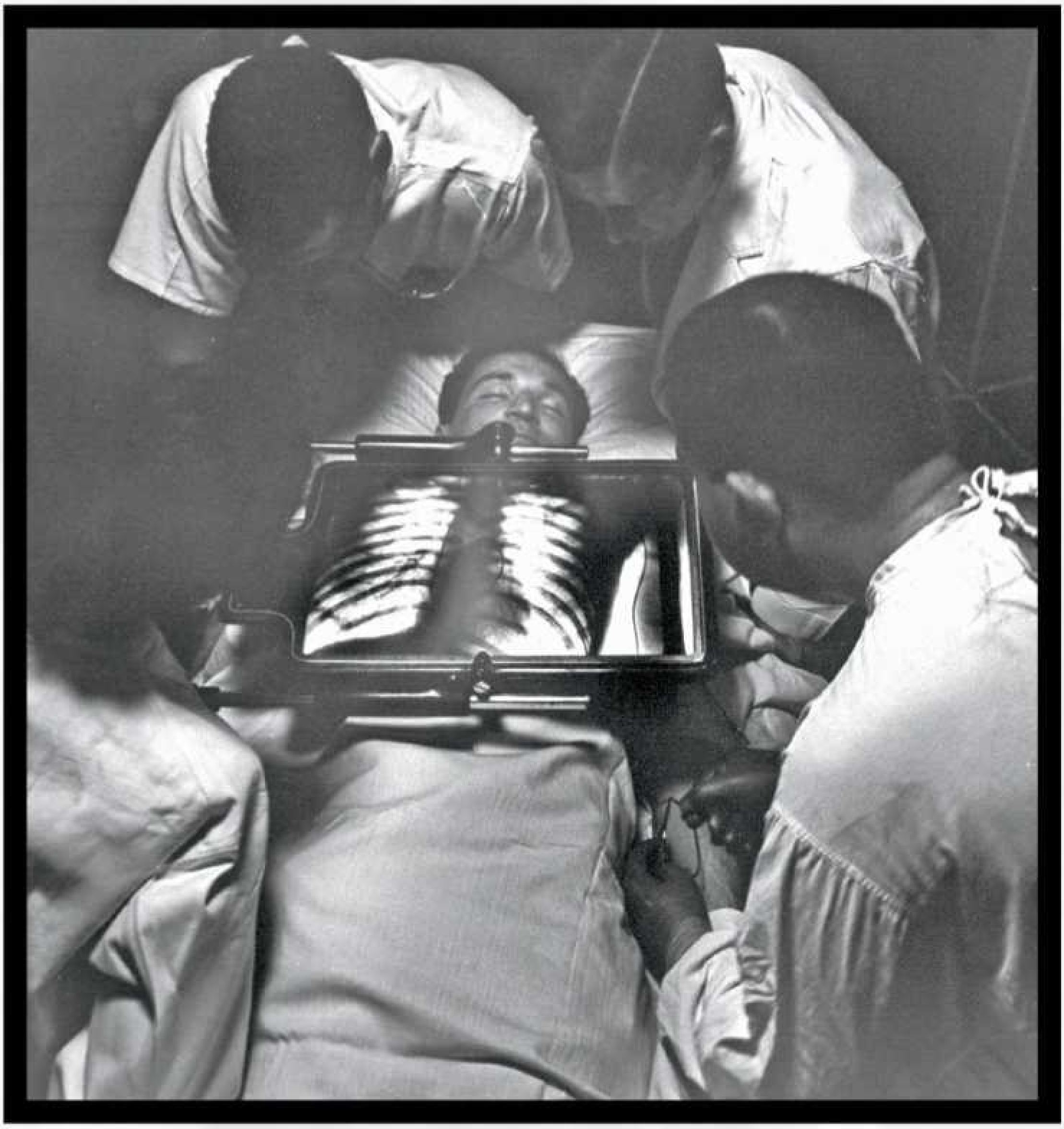
Schneider had to admit he did not know, because no one had ever been treated in this way. So he

actually allowed Forssmann to catheterize a young woman dying from a botched abortion. In an era before antibiotics, her condition appeared to transiently improve with intracardiac drug therapy before she died, but the result was inconclusive. Schneider decided the risk of continuing the experiment exceeded the benefit. He terminated Forssmann's studies on patients. Forssmann was entirely undeterred. He puttered around further, injecting X-ray contrast dye to outline the chambers of the heart in dogs, and he continued his own self-experimentation.

According to legend, Forssmann quit his research on himself only after he used up all of his veins after cutting into his blood vessels 17 times. He published his results in Germany's premier medical journal, *Deutsche Medizinische Wochenschrift*, in 1929. The medical field's reaction covered the spectrum from an indifferent shoulder shrug to intense scorn. A catheter in the heart provided no conceivable value and carried huge potential risks.

Forssmann's image among his colleagues transmogrified from stubborn misfit to dangerous madman — a misfit who disregarded the norms of his profession. His research summarily dismissed by the medical establishment, he discovered that the doors of German cardiology were firmly and irrevocably closed, and he could go no further in cardiology training.

In Berlin, he found a different specialty. Forssmann had used a urologic catheter to probe the heart, and in a bizarre twist, he entered training as a urologic surgeon. He never looked back, and never returned to cardiovascular research.



Cardiac surgeons from the 1940s use an X-ray machine to track their progress as they feed a venous catheter into a patient's heart.

AL FENN/THE LIFE PICTURE COLLECTION/GETTY IMAGES

Forssmann proved that right heart catheterization could be safe and could be used to create primitive images of the heart's chambers. For the next 10 years, however, the judgment of the medical establishment was that of outright contempt. To everyone else in the field, a pigheaded fool in a small German town had provided no useful scientific insight about the heart. Forssmann performed a dangerous parlor trick, nothing more.

But as the storms of World War II engulfed Europe, American investigators André Cournand and Dickinson Richards at Bellevue Hospital in New York reasoned they could marry Forssmann's ridiculed catheterization method to their methods of recording blood pressure, flow and images of the heart chambers. Richards focused on pressures and flow; Cournand made images by injecting an X-ray-dense dye, a process dubbed angiography.

As war erupted, their arcane research was suddenly transformed into a medical imperative. Measurement of intracardiac pressures and cardiac output guided treatment of soldiers dying of traumatic shock. War had transformed Forssmann's primitive technique into a practical tool.

After the war, with the birth of cardiac surgery, misdiagnosis became a plague. Clarence Dennis in Minnesota and John Gibbon in Philadelphia both failed on their first attempts to use their heart-lung machines on children because their cardiologic colleagues misdiagnosed the nature of their patients' heart defect. Tragically, in both cases, the child died on the operating table. To visualize the anatomic abnormalities of a child's heart prior to opening the chest, surgeons needed detailed images of the four heart chambers and the major vessels. In response, cardiologists reached for the techniques that Cournand and Richards had used.

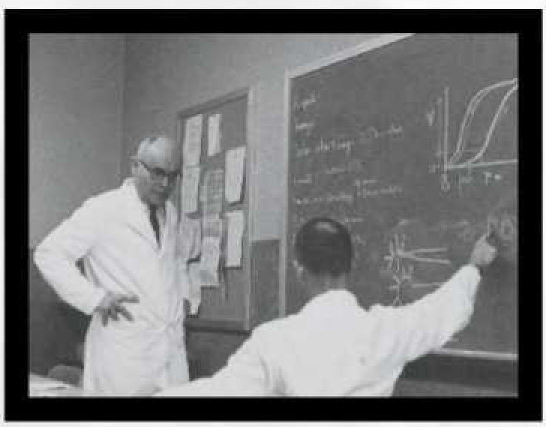
At Johns Hopkins University in Baltimore, at the behest of cardiac surgeon Alfred Blalock, Richard Bing opened America's first cardiac catheterization laboratory. In Boston, Lewis Dexter, working with Dwight Harken, also opened a lab. The early images of the inside of coronary arteries, however, were desperately primitive. The heart was in constant motion, yet images could be acquired only one at a time. The surgeons needed movies, not photographs.

Industry quickly responded by creating automatic film cassette changers that produced a stack of photographs in rapid succession, and trumped that the following year by recording images on movie film. The first films were recorded at a paltry two images per second. It wasn't a movie, but it was a start.

Today, we manipulate digital images of the heart and its vessels in colorful three-dimensional displays. Our early images were like Charlie Chaplin silent flicks compared with today's *Star Wars*. When I entered cardiology, we spent hours debating diagnosis; today, we know the diagnosis — we debate treatment.

And the rest of the story? In 1932, three years after his Eberswalde escapade, Forssmann joined the Nazi Party. When war erupted in Eastern Europe, he joined the troops as a doctor on the Russian front. As the Wehrmacht collapsed in

As war erupted, Cournand and Richards' arcane research was suddenly transformed into a medical imperative. Measurement of intracardiac pressures and cardiac output guided treatment of soldiers dying of traumatic shock. War had transformed Forssmann's primitive technique into a practical tool.



André Cournand (facing the camera in the left image) and Dickinson Richards (examining a patient in the right image) collaborated to use Forssmann's technique to improve heart imaging. The trio won the Nobel Prize in Medicine in 1956.

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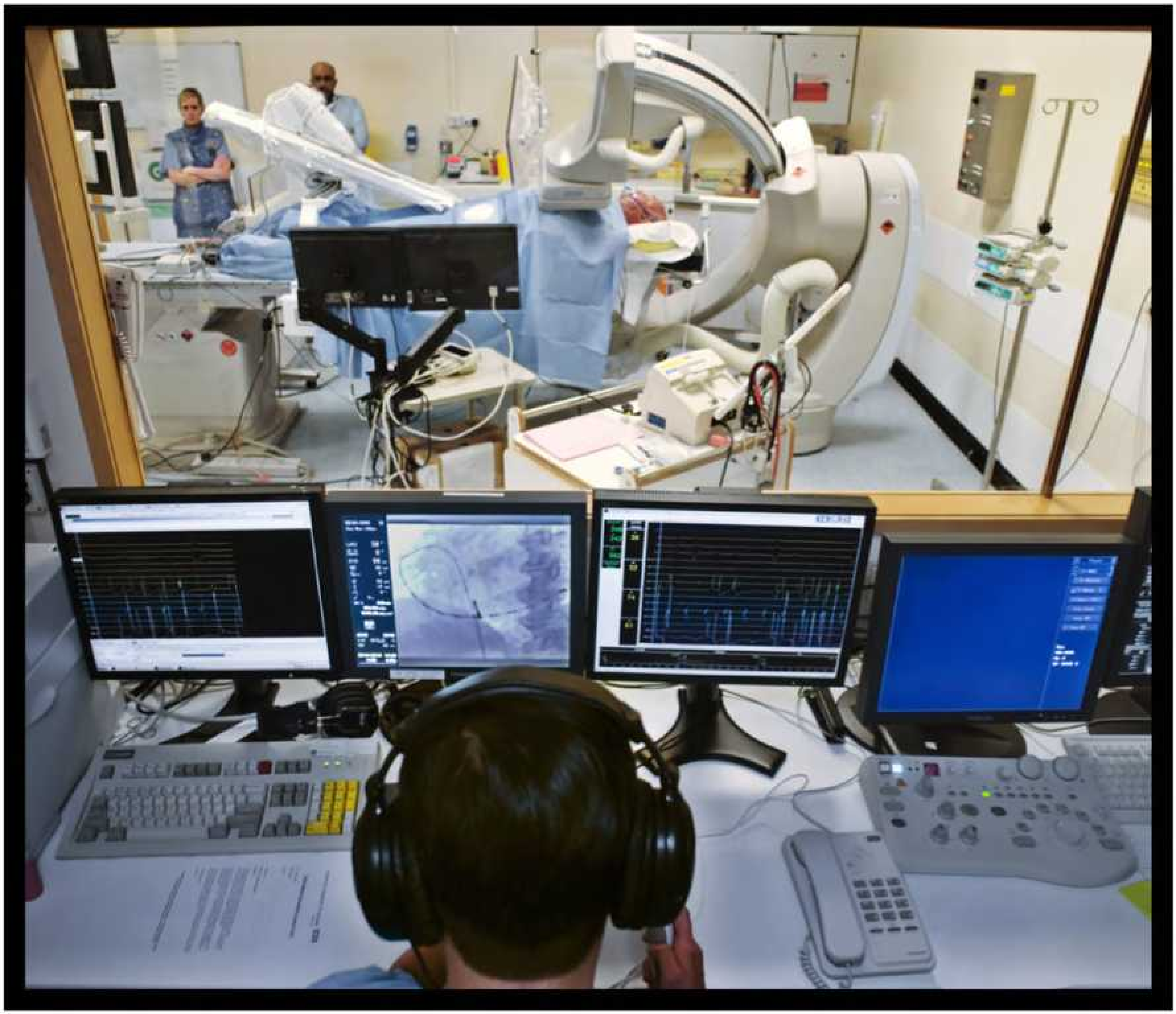


Thanks to Cournand, Richards and Forssmann, later medical inventors built on their work and brought us into the modern age of heart imaging. Today, machines monitor patients' hearts constantly and provide real-time images for doctors to conduct remote heart catheterization.

JAMES KING-HOLMES/SCIENCE SOURCE

the snowfields of Leningrad, he fled before the onslaught, ultimately reaching the river that separated Russian and American forces.

Fearing imprisonment in the notorious Russian prisoner-of-war camps, Forssmann dove into the bone-chilling water and swam to the opposite bank, to be captured, trembling and humiliated, by American forces. He had reached the low point in his life. Released at war's end, Forssmann returned to the private practice of urology. In later years, he repeatedly apologized for his involvement in the Nazi Party.

In 1956, Werner Forssmann — with no other important contribution to medical science in the years that followed his act of youthful duplicity in the Forest of the Boars — shared the Nobel Prize in Medicine with Cournand and Richards. The world of medical science had completely reversed its opinion about the events on that day.

History had decreed that the German youth who defied authority, tricked a smitten nurse to provide forbidden supplies, strapped her to a bed and proceeded with a potentially lethal experiment on himself was right, and the rest of his world was wrong. He had, the Nobel Prize proclaimed, made a monumental contribution to science.

Some have diminished Forssmann's glory by sniping that he is the least intellectual person ever to win the Nobel Prize in Medicine. Perhaps, but who among us would have done what he did? Werner Forssmann is certainly our boldest winner. D

Up in the Air

A daring treetop experiment is yielding key insights into the fate of sensitive rainforest plants as air pollution rises.

BY **SARAH HEWITT**

Wiping sweat from her face, ecologist Catherine Cardelùs inches her way up a massive tree in the Costa Rican rainforest, pushing aside tangled vines as she climbs through the understory. Her rope disappears into the thick green above. Thirty minutes later, abdominal muscles screaming, she reaches the canopy and swings her leg over a giant branch 110 feet above the ground.

The tree limb she's straddling is thick with epiphytes — plants that grow on other plants — and they're the reason she's come to this dizzying study site at the La Selva Biological Station in northern Costa Rica. Epiphytes, which support many of the canopy's wildlife and plants in one way or another, live at the interface between the atmosphere and the rainforest. That makes them especially vulnerable to increasing air pollution. Cardelùs, of Colgate University in Hamilton, N.Y., and her longtime co-researcher, Carrie Woods, want to know how two pollutants in particular — nitrogen and phosphorus — will affect epiphytes. What they find may also offer insights into how the rest of the rainforest will respond to a more polluted world.

"I consider these guys kind of the canary in the coal mine," Cardelùs says.

Despite its distance from the ground, the canopy is home to about one-third of all rainforest species. Making a living in the treetops is tough; the plants and animals here coexist in a precarious equilibrium, relying on each other for food and sometimes shelter. Epiphytes are linchpins in this aerial ecosystem: Monkeys feed on them; dragonflies lay eggs in them; and the water-filled base of epiphytes called bromeliads form nurseries for developing tadpoles. Trees with epiphytes stay cooler and lose less water.

Researcher Shannon Young, part of a team assessing the impacts of pollution on the rainforest canopy, measures treetop-dwelling plants called epiphytes in a *Lecythis ampla* tree in Costa Rica.

"There's an entire ecosystem up here," Woods says from her branch a few feet above Cardelùs, pointing out the various bromeliads and ferns sprouting from every available surface. Some leaves are an inch long; others are measured in feet. Woods has counted 65 species of epiphytes in a single tree, each one vying for nutrients and space in a highly complex and competitive system. Cardelùs suspects that nitrogen and phosphorus pollution may upset the interactions between canopy-dwelling species.

Natural processes deposit nitrogen from the air onto land and water at the rate of about 0.45 pounds per acre

CARRIE L. WOODS. MAP: MATTJEACOCK/ISTOCK

As nitrogen and phosphorus levels increase, the rainforest canopy could undergo major changes.

Top: Researcher Catherine Cardelùs climbs a tree to collect plants from the canopy. Above: Lindsay McCulloch processes samples in the La Selva lab. The team hopes to glean insights into what the future holds for this ecosystem.

CLOCKWISE FROM TOP LEFT: SARAH HEWITT; CARRIE L. WOODS (2)

Cardelùs suspects that nitrogen and phosphorus pollution may upset the interactions between canopy-dwelling species. But how do you study the impacts of future pollution?

per year. But add in human sources from burning fossil fuels, agricultural practices and energy production, and the average deposition rate jumps to 8.9 pounds per acre per year. By 2050, these rates could double as the global population rises.

"We have more people on the planet, and when you have more people, you have more cars, more industries, more buildings, more stores, and all of that leads to more pollution," says Woods. At a certain point, too much nitrogen can harm ecosystems, often by changing the chemical makeup of the soil; the threat varies greatly depending on the habitat, and researchers are still trying to understand where those thresholds are, she adds.

But how do you study the impacts of future pollution? Cardelùs devised an unusual experiment that, in effect, brings the future to the present. For the past five years, Cardelùs and Woods have added pollution to a handful of trees in the rainforest surrounding the La Selva station. Just like you'd first test a new stain remover on an inconspicuous part of your favorite jacket, the researchers want to test how an influx of nutrients will affect epiphytes, effects that Cardelùs predicts will preface changes throughout the rest of the forest.

A LAB IN THE CANOPY

Cardelùs remembers the first time she climbed a tree and realized the vastness of the epiphyte community. "I looked at a branch, and I had an entire other forest," she says, "and I thought, 'Holy cow, how does this function?'" Since 1997, she's climbed hundreds of trees in Central and North America as well as Ethiopia. Woods is equally obsessed. From another branch, she gestures toward a toucan. "When you're up here, you're living the rainforest life," Woods says. "Nothing is better."

But life in the rainforest — and all of Earth's forests — is likely to change as pollution deposits excess nutrients in the soil and air. Studies on nutrient deposition have primarily focused on the Northern Hemisphere. There, rising nitrogen levels decrease forest biodiversity. But it's unclear whether rainforests — home to the bulk of the world's biodiversity — will follow the same trend.

Enter Cardelùs' experiment in reading the future. During the five-year study, which was the first to examine the effects of projected pollution levels on the rainforest canopy, local field assistants climbed each of 10 trees at La Selva every couple of weeks — five each from two tree species, *Virola koschnyi* and *Lecythis ampla*. They hand-sprayed rainwater solutions containing nutrients onto

Given that epiphytes, like all plants, need nitrogen to survive, it's tempting to think it could help them thrive. But just as with wine, you can have too much of a good thing.

Top: A tank bromeliad, ***Guzmania lingulata.*** **Above, from left: Researchers Shannon Young, Thomas Wobby and Providence Ryan measure plants in a controlled experiment at the La Selva research lab in Costa Rica.**

the surface of five different branches, exposing each branch to a different treatment. One received normal rainwater; two were sprayed with a solution containing either 50 percent more nitrogen or phosphorus; another received both nutrients; and the last branch was partially covered to mimic less rainfall. Every summer during the study, which concluded in 2014, Cardelùs, Woods and a team of students spent countless hours suspended in midair, cataloging and sampling hundreds of epiphytes and the canopy soil they grow in.

Given that epiphytes, like all plants, need nitrogen and phosphorus to survive, it's tempting to think it could help them thrive. But just as with wine, you can have too much of a good thing. "If one group of plants is better at handling nutrient addition and they grow faster and reproduce faster, what will that mean to the other plants that can't compete as well?" asks Cardelùs.

Since epiphytes are cut off from the rich pool of forest floor nutrients, each species has to extract what it needs from the air, rainwater and scant canopy soil, with hundreds of plants tapping into the same 1-inch acidic layer that forms from decomposing organic material. "There's less soil and less resilience up there to handling changes in nutrient deposition," Cardelùs says. She fears the canopy diversity will eventually decrease.

LESSONS FROM THE SOIL

Zipping back down from the canopy to the ground, leaf and soil samples carefully stashed in backpacks, the researchers head to the lab. They tease out the twigs and debris from the compostlike soil. Back at Colgate, the team analyzes the samples for enzyme activity, microbe abundance, and nutrient content and availability. Fungi and bacteria are responsible for cycling nutrients, and in canopy soil, fungi tend to dominate. But this soil shows something different. In the nutrient-treated branches, bacteria have taken over, which is usually a sign that more nutrients are available in the system, Woods says.

This change in microscopic organisms could have big impacts. "We're shifting the entire functional composition of the soil, and there's going to be upper-level effects that we haven't even seen yet," she says. The researchers are still working through the thousands of samples they've collected, so they can't say exactly what those effects will be yet — but they'll know before the worst pollution takes hold, giving them a sneak peek of the future.

"We know a lot about the canopy ecosystem, but we still don't know very much," Cardelùs says. After all, it's not the most accessible workplace. With so many unknowns, the danger, she says, is that in polluting the atmosphere, we are tampering with interactions we don't fully understand. D

Sarah Hewitt *is a freelance writer in Calgary, Alberta.*

TOP: SARAH HEWITT. BOTTOM: CARRIE L. WOODS

The Care and Feeding of Astronauts

Early space travelers faced darkness, danger and truly terrible food.

BY CHRISTIAN MILLMAN

One small gulp for man: fruitcake from Apollo 11.

William Pogue had made an interesting — if somewhat distasteful — personal discovery. The astronaut, who piloted the third and final manned mission to the Skylab space station in November 1973, experienced a phenomenon known as a wet burp. You may laugh (or wrinkle your nose in disgust), but in space, a wet burp is no joke.

As it turns out, an environment of near-weightlessness doesn't allow the contents of your stomach to settle out by weight as they would on Earth. Gas, liquids and solids bump against the esophageal sphincter, the ring of muscular tissue that separates the esophagus from the stomach.

"The sphincter is gravity-assisted; it's not a total closure," says Vickie Kloeris, manager of the International Space Station's food systems as well as NASA's Space Food Systems Laboratory at Johnson Space Center in Houston. And if you belch in space, there could be some backflow.

In the confines of a space vehicle, that could be messy, even troublesome. Unless the astronaut can keep the mouth closed and reswallow that backflow — which Pogue heroically managed to do — any liquids or solids ejected during a wet burp could conceivably float off and lodge in sensitive instruments. Kloeris says this isn't a huge concern, but back on Skylab, Pogue was worried enough — or possibly just grossed out — by this prospect that he limited his belches to just two during his entire 84-day mission.

Well before Pogue learned he could never trust a burp, others had struggled with more rudimentary issues: Did humans even *have* the ability to eat or drink in space? Would they be able to swallow without gravity? Could food make the necessary transit through the entire gut for nutrients to be properly absorbed?

In April 1961, Yuri Gagarin, the first human in space, began to put those questions to the test while orbiting the Earth aboard the Soviet Union's *Vostok 1*. He squeezed two toothpaste-like tubes of pureed meat and one of chocolate into his mouth (presumably not at the same time) and swallowed

Skylab's William Pogue (left) had a close encounter with a wet burp. Earlier astronauts would have envied Skylab's menu. Food during Project Gemini came in pouches (above). Mercury hero John Glenn dined on applesauce in a tube (below).

OPPOSITE FROM TOP: ERIC LONG/NATIONAL AIR AND SPACE MUSEUM/SMITHSONIAN INSTITUTION; UNDERWOOD ARCHIVES/GETTY IMAGES; NASA (2)
THIS PAGE, CLOCKWISE FROM TOP LEFT: NASA; NATIONAL AIR AND SPACE MUSEUM/SMITHSONIAN INSTITUTION; NASA; RAY CUNNINGHAM; NASA (2)

hard. It worked.

On this side of the Cold War, it took almost a year for Project Mercury to seat an American astronaut at an extraterrestrial table. When John Glenn blasted off in *Friendship 7* in February 1962, he was provisioned with tubes of pureed beef and vegetables, applesauce and, yes, powdered envelopes of Tang. (Contrary to common belief, Tang wasn't invented by NASA. General Mills had been serving it to earth-bound drinkers since 1957. It's now owned by Kraft.)

So swallowing proved not to be entirely dependent on gravity. And thankfully, the pythonlike digestive process of peristalsis, which moves food and drink along in wavelike contractions from first swallow to final farewell, was likewise unimpeded by a zero-gravity environment. With that uncertainty dispelled, the astronauts of the remaining few years of Project Mercury continued to grimace their way through more such food in tubes.

On Skylab (above), food choices were a giant leap ahead of previous missions. Meal trays (below) each contained heating elements for prepping individual food packets from a menu of over 72 items.

THE WRONG STUFF

In the mid-1960s, food didn't get a whole lot better for Project Gemini, which focused on the longer missions necessary to test the skills and equipment needed to get to the moon. If Mercury's food had been defined by a tube, Gemini's was characterized by a pouch. Forget faint praise; this straightforward description from the Smithsonian National Air and Space Museum damns it best: "Dehydrated, freeze-dried, and bite-sized foods, coated with gelatin or oil to prevent crumbling."

Space eats (from top): an aluminum food tube from the Mercury missions; Apollo-Soyuz astronauts Thomas Stafford and Deke Slayton holding tubes labeled "vodka" (but really borscht); a commemorative corned beef sandwich at the Virgil I. Grissom Memorial museum; and a food rehydrator on the ISS.

Gemini-style pouches epitomize the food many people still associate with space travel, thanks to the inexplicable popularity of freeze-dried astronaut ice cream, ever a hit among kids passing through museum gift shops. In

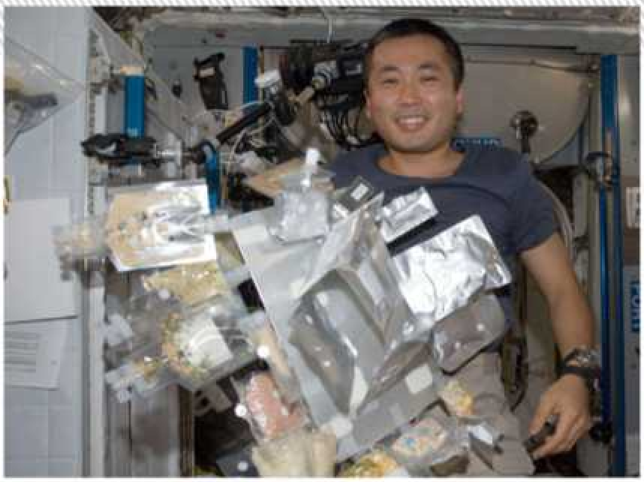
actuality, those dried foam cubes made it into space only once before being abandoned because of their grotesque texture and ill flavor.

The Gemini mission also clearly illustrated something prison administrators and ship captains have known for a long time: People confined to small spaces for extended periods focus with near-obsession on the quality, quantity and variety of food. A riotous insurrection of sorts even broke out over food that the astronauts almost universally despised. When Gemini 3 commander Gus Grissom entered space in March 1965, he was one of the most vocal and persistent critics of the space-cowboy chow.

Unknown to anyone else, his co-pilot John Young had hatched a sly plan to remedy the situation. Shortly after the two settled into Earth orbit, Young reached into a spacesuit pocket and grinned at Grissom. "You care for a corned beef sandwich, skipper?" he asked as he handed over a smuggled surprise. A delighted Grissom happily tore off a few bites before he had to abandon the sandwich because of the cloud of floating rye bread bits it caused.

Few were laughing on the ground. Congress hastily convened a hearing to determine if the stowaway sandwich and its crumbs presented any risk to the fledgling space program — the nation's crown jewel in the 1960s — and its craft. After hangdog NASA handlers promised it wouldn't happen again, no further action was taken against Young or Grissom for their deli devilry.

By the time the Apollo 11 mission was on the launchpad for its historic trip to the lunar surface in July 1969, we may have figured out how to send a man to the moon, but we hadn't yet figured out how to send good food with him. Instead of being forced to rely on Gemini's cold freeze-dried foodstuffs, Apollo astronauts were forced to rely on hot freeze-dried foodstuffs. This included a breakfast item memorably described by one of its testers as "coarse granulated rubber with a sausage flavor."



Aboard the ISS, astronauts like Koichi Wakata enjoy a range of food choices to avoid the dreaded "menu fatigue" that plagued earlier explorers.

Although their caloric intake was upped 300 calories to 2,800 per day, Apollo astronauts continued to have the same worrisome issue as the earlier astronauts who spent more than a day or two in space: They ate so little, they lost significant weight. That's bad news if you want to be able to leave Earth for extended periods — and NASA did.

HOUSTON, WE *HAD* A PROBLEM

Faced with near-universal dissatisfaction, post-Apollo planners knew they had real difficulties to address before they sent astronauts to the first American space station, Skylab. The planned missions of one to three months would be in jeopardy if crews couldn't tolerate the food for that period of time.

Even though it hosted only nine people — in three crews of three astronauts each — between its launch in 1973 and its flaming, uncontrolled atmospheric re-entry in 1979, Skylab had the most diner-friendly food system yet. Its menu of 72 items included frozen and refrigerated foods, something never replicated before or since. Pogue's gastric dilemma notwithstanding, Skylab's dietary improvements worked. For the first time, astronauts did not return to Earth weighing less than when they left.

The experiences on Skylab continue to inform the way crew members eat aboard the International Space Station, which has been continuously occupied by up to six people at a time since November 2000. And those experiences also illuminated the daunting challenges facing those who hope to send humans to Mars, says Kloeris. "Menu fatigue remains a real problem that could degrade crew performance on a Mars mission," she says.

But there are logistical challenges to overcome as well. A mission to Mars could require as much as 3,000 pounds of food per person, all of which needs to have a shelf life of around five years. "We can make food that will last that long," Kloeris says. "The challenge is what the quality of the food will be."

But what happens after the crew eats that food? Kloeris allows that astronauts shouldn't expect to hold in a belch for an entire mission on the ISS, let alone to the Red Planet. But NASA has no formal procedure or position on the matter, and the problem isn't usually discussed by astronauts during post-mission debriefings, Kloeris notes.

"It's not brought up often, so to speak," she says. Like Pogue (and no doubt many other astronauts after him), at some point they'll likely have to grit their teeth, swallow hard and get back to work. D

Writer ***Christian Millman*** *has never been in a zero-g environment, but he has replicated the wet burp phenomenon here on Earth. He doesn't recommend the experience.*

Subscribers, check out the menu at **DiscoverMagazine.com/FakeMars**, a four-month simulated mission.

NASA

New Horizons probe (left) revealed Pluto as a colorful world, with a "heart" composed of nitrogen and methane ices.

The Passion of the Pluto-Philes

At New Horizons mission control, a 12-watt signal from 3 billion miles away unleashed a surge of scientific emotion.

BY **COREY S. POWELL**

On July 14, I was driving back to Johns Hopkins University's Applied Physics Lab in Laurel, Md. — mission control for the New Horizons spacecraft — when I suddenly found myself swept up in an interplanetary race. Earlier in the day, I huddled with the science and engineering teams as the probe completed its historic Pluto flyby.

Or rather, as we all *hoped* it had. We wouldn't know for sure until New Horizons' "mission accomplished" signal arrived, and because of the enormous distance involved, that signal would take a tedious 4.6 hours to reach Earth. So we all took a break while waiting for the triumphant message, due to arrive at 8:53 p.m.

Just as I pulled into the parking lot, prepared to join the vigil, I realized with a sinking sensation that I had left my laptop behind at dinner. I did a quick calculation. The 5-mile trip to the restaurant would take about 10 minutes, plus another 10 minutes to get back. It was 8:30. Possible, if I made perfect time. I had no choice; all my notes and files were on that computer.

As I passed the slower cars and tried to beat the traffic lights, it struck me: I was trying to outrun a radio beam, heading Earthward at the speed of light. Twenty minutes to go, and the signal had already crossed Jupiter's orbit; 10 minutes to go, and it was past the asteroid belt.

I sprinted into the main conference room with two minutes to spare — I beat the beam by 22 million miles. As I entered, I heard the flight engineers tick off a checklist of perfect readings. I watched New Horizons project leader Alan Stern beam incandescent at the success of his mission. I waved a small U.S. flag in unison with the rest of the crowd. And I shared the Pluto scientists' thrill at having caught up with the dispatches from the edge of the solar system.

THE DAM BREAKS

Those dispatches have been a long time coming. Stern first proposed a NASA mission to Pluto in 1990. It got no traction. A succession of follow-up proposals fared better, but still not well enough. One of them, called Pluto Kuiper Express, got as far as the design stage before it was abruptly canceled in 2000. Even when New Horizons was finally approved, budget cuts effectively terminated it in 2002. The scrappy probe managed a rare resurrection after getting staunch support from the National Academy of Sciences and the community of outer-planet researchers, along with passionate lobbying by The Planetary Society, a nonprofit group.

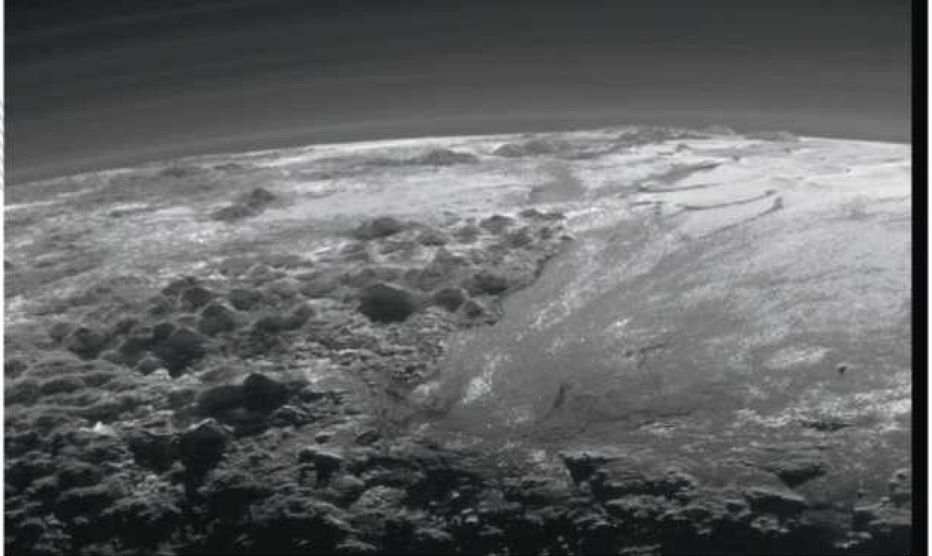
The crowd at New Horizons mission control counts down to the spacecraft's closest approach to Pluto on July 14.

Further boosting the historical resonances, the New Horizons Pluto flyby occurred 50 years to the day after Mariner 4 sailed past Mars and returned the first images of a planet from deep space. That's either a very slow or very quick achievement, depending on your perspective. John Grunsfeld, head of NASA's Science Mission Directorate, opted for the latter, telling the celebrants in Laurel, "Five hundred years from now, we will look back on this as the golden age of exploration."

All of the delayed — and nearly denied — gratification behind New Horizons was obvious in the rapturous applause after the 8:53 p.m. signal. But the scientists gathered at the Applied Physics Lab had not come for closure. Now that they finally had caught up with Pluto, Stern and his many cohorts were fixated solely on the future. In the new view, Pluto is no longer the last planet, but rather the first and largest member of the Kuiper Belt, a population of billions of frozen comets and a handful of planetlike bodies beyond Neptune. As Grunsfeld put it, "We've opened up a new realm of the solar system."

New Horizons is giving us our first look at this entirely uncharted class of objects. The Kuiper Belt began to take shape 4.5 billion years ago, early in solar system history, and it has evolved separately from all the other worlds we know. It preserves the gases and organic molecules that circulated as

TOP: NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/SOUTHWEST RESEARCH INSTITUTE (2); NASA/BILL INGALLS



Just 15 minutes after closest approach, New Horizons captured a near-sunset view of Pluto's rugged terrain and hazy, layered atmosphere. The scene is 230 miles across.

Earth was forming, and it has a unique chemical and geologic history. Nobody knew what to expect from Pluto.

Ellen Stofan, NASA's chief scientist, was rendered briefly speechless when she saw the first full close-up Pluto portrait circulating around the lab July 15. She wondered aloud: Where are all the craters? Is the surface geologically active? How old is it? Stofan misted up as she reflected on the storied path that had brought humanity to Pluto. "I don't normally cry when I see planetary images," she apologized, before adding, "OK, sometimes I do, especially if it's Titan."

The acute sense of adventures ahead — not of obstacles left behind — dominated the emotions at mission control. Alan Stern, tightly controlled until he heard the all-clear signal, pumped his fist, uncurled a mad grin and exclaimed, "We did it!" Jeffrey Moore, a co-investigator on New Horizons, giggled that the first look at Pluto "blows my mind, blows everyone's mind." Fran Bagenal, another co-investigator and team veteran, confided that she was "jumping up and down" as each new image downloaded.

Meanwhile in the main conference hall, Pluto enthusiasts were passing around a model of New Horizons that could be worn as a hat. People took turns snapping photos, often waving the unofficial Pluto salute: nine fingers held up in solidarity with the former ninth planet. Five minutes in that room would cure anyone of the misconception that scientists are not emotional people.

UNEXPECTED ACTIVITY

The initial messages from New Horizons can be summed up in those three words that make any researcher smile: surprise, surprise, surprise. Start with that largely crater-free surface that Stofan marveled over.

The general assumption had been that objects in the Kuiper Belt should be geologically inactive because they are so cold. But the first New Horizons views revealed expansive, smooth plains in some areas that appear to be no more than 100 million years old, quite youthful in geologic terms. The images also showed a range of 11,000-foot-high ice mountains, flowing glaciers of frozen nitrogen and a pervasive coating of organic compounds that has painted the whole world pinkish-red.

"We now have an isolated, small planet that is showing activity after 4.5 billion years," Stern told the crowd at the Applied Physics Lab. "It will send a lot of geophysicists back to the drawing board to figure out how that works."

Even more shocking, Pluto's biggest moon, Charon — just 751 miles wide — also shows a dynamic, rifted surface, with a dark smudge at the north pole, possibly methane captured from Pluto's thin atmosphere. At the same time, Charon's colors and overall geology look drastically different from Pluto's, for reasons only vaguely understood. "It just blew our socks off!" exclaimed Cathy Olkin, deputy project scientist for New Horizons, to another round of applause.

Enthusiasts (left) display the Pluto salute and New Horizons hat; project leader Alan Stern (below) is perhaps the ultimate Pluto enthusiast.

The dispatches from New Horizons are still coming in long after the crowd departed. The probe's modest data-transmission rate means that the full Pluto data set will not reach Earth until October 2016. All of the eye-popping discoveries reported during the flyby events were based on just the first 2 percent of data returned. While the scientific lessons of New Horizons are just starting to sink in, the main message has already come through loud and clear. The worlds of the Kuiper Belt are lively and diverse, unlike anything humans have seen before.

But Stern had one last surprise that night. "I've been secretly working on a Pluto lander," he blurted out after unveiling the initial New Horizons images. People laughed good-naturedly, but then he cut them off: "I'm serious."

And why not? Now that we've caught up with Pluto, we have a sense of just how much more adventure and excitement awaits out there. The only question is, do we have the resolve to continue the race? D

Corey S. Powell**, editor at large of* Discover, *also writes the magazine's Out There blog. Follow him on Twitter:* ***@coreyspowell

FROM TOP: NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/SOUTHWEST RESEARCH INSTITUTE; COREY S. POWELL; NASA/BILL INGALLS

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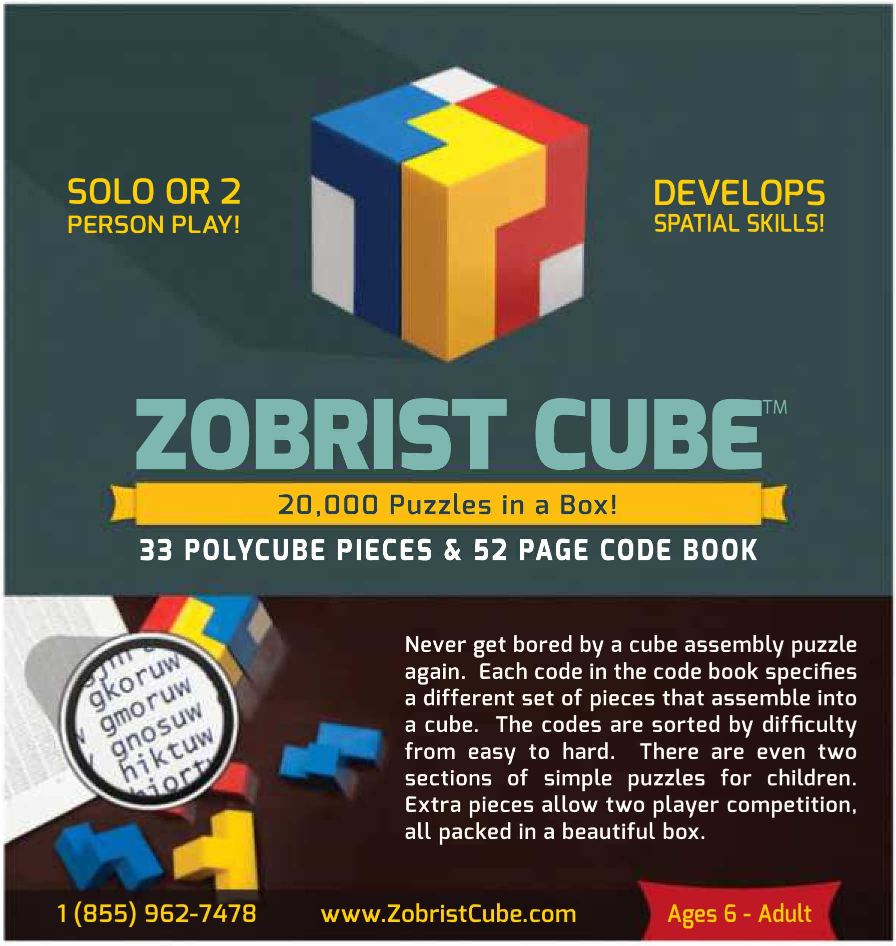


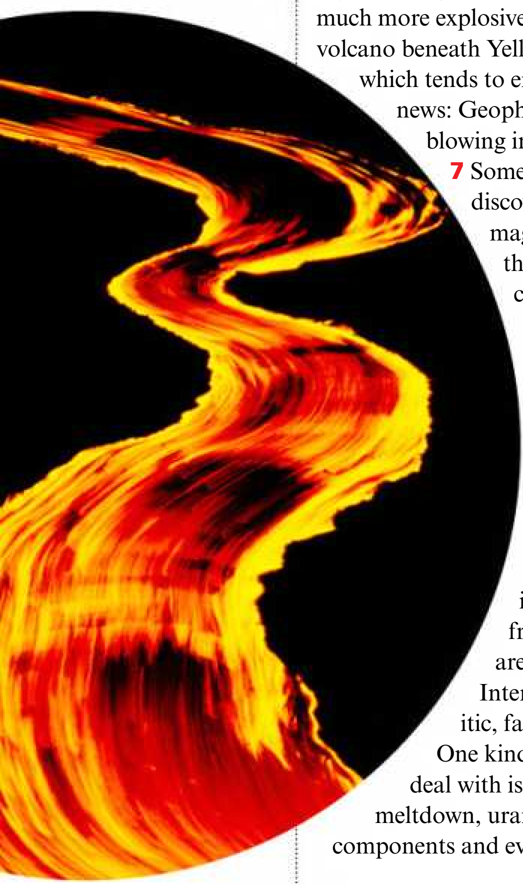
20 Things You Didn't Know About ...

Lava

BY **GEMMA TARLACH**

Researchers get a front-row seat to a stunning display of lava and sparks from Sicily's Mount Etna.

Basaltic lava, the most common type on Earth, is found throughout Hawaii's Volcanoes National Park in both cooling formations that resemble cake batter (above) and in hotter, faster-moving rivers (below).



1 Lava wasn't called lava until Mount Vesuvius erupted in 1737. Francesco Serao used the word, derived from *labes* ("fall" or "slide" in Latin), to compare the hot ooze on the volcano's slopes to mudslides after a heavy rain. **2** Lava is magma that has erupted above the planet's surface. The most common variety of molten rock, either above ground or below, is basalt. **3** Basaltic lava the world over is classified with the Hawaiian words *a'a* or *pahoehoe* based on consistency. Pahoehoe tends to spread slowly — imagine cake batter poured into the center of a pan. **4** A'a lava, on the other hand, often advances erratically, including occasional sudden surges. The same eruption of lava can switch from pahoehoe to a'a, depending on factors such as thickness and how fast it's cooling. **5** Be glad other types of lava aren't as common. Both andesitic and rhyolitic magma have higher gas content and erupt much more explosively than basaltic. **6** The supervolcano beneath Yellowstone has rhyolitic magma, which tends to erupt catastrophically. Some good news: Geophysicists put the chance of it blowing in any given year at 1 in 700,000. **7** Some bad news: In 2015 researchers discovered Yellowstone has even more magma than we thought. Beneath the previously known magma chamber, there's a second, larger reservoir with enough hot goo to fill the Grand Canyon 11.2 times. **8** Lava can be typed by chemical signature as well. Basaltic lava is mafic, an abbreviation of two of its prevalent elements, magnesium and *ferrum*, derived from the Latin word for iron. **9** Rhyolitic lava is felsic; the name is derived from feldspar and silica, which are present in high concentrations. Intermediate lavas, including andesitic, fall somewhere in between. **10** One kind of lava you *really* don't want to deal with is corium lava. During a nuclear meltdown, uranium dioxide fuel, fuel rod components and even the reactor become superheated — as much as 3,600 degrees Fahrenheit — and melt together to form corium, which can eat through containment systems. **11** Although technically not lava, corium mimics its movement. The Elephant's Foot, a highly radioactive corium glob that formed beneath the Chernobyl reactor during the 1986 disaster, looks remarkably like a cooled basaltic flow. **12** "Blue lava" is also not lava. The vivid electric-blue color of flows down the side of Indonesian volcano Kawah Ijen is actually caused by sulfuric gas released at the same time as plain-old basaltic lava. **13** The color of real lava is instructive, however. The lighter the color, the more fluid the lava: Bright orange indicates temperatures at 1,000 degrees Celsius and higher, while dark red is a comparatively cool 650 to 800 C. **14** Nearly black natrocarbonatite lava is an exception. It's found in just one spot: Tanzania's Oldoinyo Lengai volcano. The sodium-enriched lava is still fluid at just 540 C. **15** When completely cool, natrocarbonatite lava turns silvery, creating an otherworldly landscape around the volcano. **16** Our solar system's largest volcano, Mars' Olympus Mons, is composed of layers of ancient eruptions of basaltic lava. At about three times the height of Mount Everest, that's a lot of lava. **17** Jupiter's moon Io continues to spew massive fountains of hot lava. In August 2013, during a two-week period of intense activity, curtains of lava gushed from fissures hundreds of miles long. **18** Further afield, things get even hotter. Astronomers have identified at least four exoplanets, including Kepler-78b, likely covered in lava. **19** Earth was also awash with lava once, in our planet's early days. In 2013 researchers suggested that these lava oceans were layered by density. Outer layers of lava and crystallized rock insulated deeper, superdense magma that remained hot for much longer than originally thought. **20** Did lava kill the dinosaurs? Maybe. About 65 million years ago, a massive basaltic lava flow covered much of India. The eruptions that created the flow released enough toxic gas to off *T. rex* and company, and may have been triggered by the asteroid that smacked into the other side of the planet at roughly the same time. D

Senior Associate Editor ***Gemma Tarlach*** *has stood on lava on all seven continents. It was cool.*

FROM TOP: NATIONAL GEOGRAPHIC CREATIVE PHOTOS BY CARSTEN PETER; MARC MORITSCH; FRANS LANTING

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